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THESIS

MODELING METHODOLOGIES FOR REPRESENTING URBAN CULTURAL GEOGRAPHIES IN STABILITY OPERATIONS

by

Todd P. Ferris

June 2008

Thesis Advisor:	Thomas W. Lucas
Second Reader:	Jonathan K. Alt

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13. ABSTRACT (maximum 200 words)

This thesis addresses Department of Defense (DoD) Modeling and Simulation (M&S) deficiencies in military and organizational societal modeling methods. These deficiencies are even more important today due to Stability Operations being an extremely prevalent mission for U.S. forces in this century. Research efforts in this thesis focused on the implementation of three analytic social theory models into the agent-based model (ABM) Pythagoras 2.0.0, in an effort to provide modeling methodologies for a single simulation tool capable of exploring the complex world of urban cultural geographies undergoing Stability Operations in an irregular warfare (IW) environment. While the individual model mappings proved to be somewhat difficult, the consolidation of all three model mappings into Pythagoras 2.0.0 proved to be infeasible with respect to capturing accurate attitudinal shifts. Civilian populaces' attitudinal shifts are functions of issues believed important by the various subpopulations comprising the civilian populaces, experienced influences, economic security, and influence exchange across social networks. With the use of simulation, statistical analysis, and cultural and societal modeling, this thesis identifies a major limitation causing significant attitude representation errors within the Pythagoras modeling environment; there is currently no direct link between experienced influences and attitudinal shifts. Funding has been allotted by TRAC-Monterey and the Marine Corps Combat Development Center (MCCDC) in Quantico, Virginia for Northrop Grumman to implement the recommended modifications provided from this research.

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MODELING METHODOLOGIES FOR REPRESENTING URBAN CULTURAL GEOGRAPHIES IN STABILITY OPERATIONS

Todd P. Ferris
Major, United States Marine Corps
B.S., United States Naval Academy, 1996

Submitted in partial fulfillment of the
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June 2008

Author: Todd P. Ferris

Approved by: Thomas W. Lucas
Thesis Advisor

Jonathan K. Alt
Second Reader

James N. Eagle
Chairman, Department of Operations Research

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ABSTRACT

This thesis addresses Department of Defense (DoD) Modeling and Simulation (M&S) deficiencies in military and organizational societal modeling methods. These deficiencies are even more important today due to Stability Operations being an extremely prevalent mission for U.S. forces in this century. Research efforts in this thesis focused on the implementation of three analytic social theory models into the agent-based model (ABM) Pythagoras 2.0.0, in an effort to provide modeling methodologies for a single simulation tool capable of exploring the complex world of urban cultural geographies undergoing Stability Operations in an irregular warfare (IW) environment. While the individual model mappings proved to be somewhat difficult, the consolidation of all three model mappings into Pythagoras 2.0.0 proved to be infeasible with respect to capturing accurate attitudinal shifts. Civilian populaces' attitudinal shifts are functions of issues believed important by the various subpopulations comprising the civilian populaces, experienced influences, economic security, and influence exchange across social networks. With the use of simulation, statistical analysis, and cultural and societal modeling, this thesis identifies a major limitation causing significant attitude representation errors within the Pythagoras modeling environment; there is currently no direct link between experienced influences and attitudinal shifts. Funding has been allotted by TRAC-Monterey and the Marine Corps Combat Development Center (MCCDC) in Quantico, Virginia for Northrop Grumman to implement the recommended modifications provided from this research.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

ABM	Agent-Based Modeling
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CF	Coalition Forces
CF_Security_PG	Coalition forces providing security; actions perceived as good
CF_Security_PB	Coalition forces providing security; actions perceived as bad
CF_TargetTerrorists_PG	Coalition forces targeting terrorists; actions perceived as good
CF_TargetTerrorists_PB	Coalition forces targeting terrorists; actions perceived as bad
COIN	Counterinsurgency
CRS	Congressional Research Service
DIME	Diplomatic, Informational, Military, Economic
DoD	Department of Defense
DoDD	Department of Defense Directive
DOE	Design of Experiment
FY	Fiscal Year
HBR	Human behavior representation
HN	Host Nation
HN_PM_PB	Host Nation Political Machine Perceived Bad
HN_PM_PG	Host Nation Political Machine Perceived Good
I_ES	Insurgency Economic Security
IW	Irregular Warfare
M&S CO	Modeling and Simulation Coordination Office
M&SSC	Modeling and Simulation Steering Committee
MAS	Multi-Agent System

MCCDC	Marine Corps Combat Development Center
MCWL	Marine Corps Warfighting Laboratory
NOLH	Nearly Orthogonal Latin Hypercube
NPS	Naval Postgraduate School
OAD	Operations Analysis Division
PF_ES	Production Force Economic Security
PF_ILT_HN	Production Force Initially Leaning towards Host Nation
PF_ILT_I	Production Force Initially Leaning towards the Insurgency
PMESII	Political, Military, Economic, Social, Infrastructure, and Information
RDT&E	Research, Development, Test, and Evaluation
RUCG	Representing Urban Cultural Geography
S1	Subpopulation 1
S2	Subpopulation 2
S1_FAM	Subpopulation 1 Family Network
S1_ILT_HN	Subpopulation 1 Initially Leaning Toward Host Nation
S1_ILT_I	Subpopulation 1 Initially Leaning Toward Insurgency
S1_PF_ILT_HN	Subpopulation 1 Production Force Initially Leaning Toward Host Nation
S1_PF_ILT_I	Subpopulation 1 Production Force Initially Leaning Toward Host Insurgency
S2_FAM	Subpopulation 2 Family Network
S_ES	Soldiering Economic Security
SECDEF	Secretary of Defense
SEED	Simulation, Experiments, and Efficient Design
SME	Subject Matter Expert
SSTR	Stability, Security, Transition, and Reconstruction
Terrorist_vCF_PG	Terrorists targeting coalition forces; actions perceived as good

Terrorist_vCF_PB	Terrorists targeting coalition forces; actions perceived as bad
Terrorist_vPF_PG	Terrorists targeting production force civilians; actions perceived as good
Terrorist_vPF_PB	Terrorists targeting production force civilians; actions perceived as bad
TRAC	TRADOC Analysis Center
TRADOC	Training and Doctrine Command
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics

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EXECUTIVE SUMMARY

This thesis addresses a major limitation in Department of Defense (DoD) Modeling and Simulation (M&S) identified by the M&S Coordination Office (M&S CO): Human Behavior Representation (HBR). The M&S Steering Committee (M&SSC) produced the M&SSC Common and Cross-Cutting Business Plan in November 2006 in order to focus DoD-wide M&S efforts toward essential M&S gaps. One extremely important gap addressed is the deficiency in military and organizational societal modeling methods. This is disconcerting, considering the majority effort—called Stability Operations—of United States forces in this century, and most likely, for years to come. The importance of Stability Operations in today's world arena has been acknowledged by DoD and, thus, such operations were pronounced equal in importance to combat operations by Department of Defense Directive (DoDD) 3000.05 in November 2005.

This research is sponsored by Training and Doctrine Analysis Center (TRAC) Monterey, California. TRAC-Monterey constructed a Representing Urban Cultural Geography (RUCG) project team with a primary objective of developing a modeling framework capable of representing civilian populaces and their attitudinal postures, while experiencing Stability Operations in an irregular warfare (IW) environment. The RUCG project team developed an analytic social theory model suite comprising three analytic models: an Attitude Effect Model, a Social Network Model, and an Economic Insurrection Model. These models, and the algorithms therein, were derived from background research in the fields of sociology, economics, and international relations.

The overarching objective for this research is the implementation of the RUCG analytic social theory model suite into the agent-based model (ABM) Pythagoras 2.0.0. Although Pythagoras is primarily a combat model, Version 2.0.0 is a recent upgrade designed to offer improved capabilities to model intangibles, such as attitudinal responses. The results of this research are intended to not only help close DoD HBR M&S gaps, but also to offer modeling methodologies and a single platform capable of

exploring the complex world of urban cultural geographies undergoing Stability Operations. This, in turn, will provide us with greater ability to investigate the integral factors and interactions among Political, Military, Economic, Social, Infrastructure, and Information (PMESII) actions utilized in Stability Operations today and in the future.

The research question and objective addressed for this research are, respectively:

- Can a representative modeling framework for the RUCG analytic social theory model suite be implemented with Pythagoras 2.0.0?
- Provide detailed documentation of all successful and unsuccessful modeling methodology mappings, as well as recommendations of enhancements, with respect to Pythagoras 2.0.0.

We initiate our analysis by implementing each of the three RUCG analytic social theory models individually into Pythagoras 2.0.0, and then expanding the framework to encompass all three. Our model mappings are driven by the social theory model suite algorithms and focus on measuring attitudinal shifts for various segments of a civilian populace facing constant attempted influence from outside interests. Attitudinal shifts are functions of issues believed important by various subpopulations comprising the civilian populace, experienced influences, economic security, and influence exchange across a social network. While the individual model mappings proved to be somewhat difficult, the consolidation of all three model mappings into Pythagoras 2.0.0 proved to be infeasible with respect to capturing accurate attitude representations.

Numerous limitations were discovered during our research; however, one major limitation prevents the successful implementation of the RUCG analytic model suite into Pythagoras 2.0.0. This limitation is the absence of a link between attributes and colors. Attributes represent the various issues civilians believe important and colors represent the attitudinal stances of the civilians, based on their levels of satisfaction with respect to these issues. In the absence of this link, no matter how much effective influence is injected onto the civilian populace during the simulation, there is no registered impact on the attitudinal stances of those influenced. Therefore, we develop a methodology within Pythagoras 2.0.0 and a separate spreadsheet model to create this essential link between attributes and colors. This methodology is the only manner in which to create this link and, unfortunately, doing so induces three significant sources of attitude representation error: priority lag color loss error, trigger train color loss error, and inaccurate social network influence exchange errors.

Priority lag color loss is a phenomenon that enables effective influences, introduced with respect to lower priority issues, to be partially or completely dominated by higher priority issues. This results in effective influence going unregistered, and subsequently disrupts accurate attitude representation. Trigger train color loss refers to multiple undesirable transfers of agents through alternate behaviors that consume the simulation's computational time. Trigger trains also amplify the negative impact of priority lag. The most significant attitude representation error resulting from our forced methodology is the social network exchange error. Influence that is exchanged across the social network is derived from relative issue differentials. Pythagoras 2.0.0 is unable to maintain accurate differentials with its current functionalities and, thus, influence exchange across the social network is extremely inaccurate.

We conduct a simulation experiment that utilizes a Nearly Orthogonal Latin Hypercube (NOLH) design matrix. Our response variable of interest is attitude representation and our factors of interest are influence magnitudes per various issues, which are all quantitative measures. We vary the four factors across 20 levels and are able to efficiently sample the potential design space with only 17 design points. To shed light onto the benefits of the NOLH design, our resultant 17 design points provide us with sufficient information to quantify the three attitude representation error sources, compared to the 160,000 design points required for a gridded design, which would produce similar results.

The results from this simulation experiment are applicable to our specific experimental design and are as follows:

- Priority lag color loss and trigger train color loss induce an overall mean percent error in attitude representation of approximately 24%.
- The mean percent attitude representation error due to inaccurate influence exchanges across the social network accumulates to greater than 70%.

To minimize and/or eliminate the errors stemming from the necessity to create an indirect link between attributes and colors, which prevents effective HBR within Pythagoras 2.0.0, we recommend the following modifications:

- Implement a capability for simulation agents to self-apply color changes in order to prevent utilization of multiple alternate behaviors to achieve those changes. This minimizes both priority lag color loss and trigger train color loss, and also removes required workaround methodologies that prevent the implementation of certain characteristics within the Economic Insurrection Model.
- Incorporate list entry functionality for color measurement triggers that utilizes true and false logic. This will eliminate trigger train color loss by preventing the simulation from wasting valuable computational time transferring agents through multiple alternate behaviors.
- Remove required bounded entries for monitoring attribute fluctuations and/or add modified attribute measurement triggers that monitor increments and decrements in attribute values. This will fix the corrupted issue differentials populating the social network.

We conclude that the current functionalities offered by Pythagoras 2.0.0 are not capable of effectively capturing the essence of the RUCG analytic social theory model suite without modifications encompassing the recommendations provided. Funding has been allotted by TRAC-Monterey and the Marine Corps Combat Development Center (MCCDC) in Quantico, Virginia for Northrop Grumman to implement the recommended modifications provided from this research. Once instituted, we believe the modified Pythagoras modeling environment will be able to effectively explore the complex world of HBR. More specifically, with respect to the TRAC-Monterey RUCG project team's objectives and current real-world operations, it will be able to investigate the effect of PMESII actions on the attitudinal responses of a civilian populace undergoing Stability Operations in an IW environment.

I. INTRODUCTION

> . . . any sound revolutionary war operator (the French underground, the Norwegian underground, or any other European anti-Nazi underground) most of the time used small-war tactics—not to destroy the German Army, of which they were thoroughly incapable, but to establish a competitive system of control over the population.[1]
>
> –Professor Bernard B. Fall

A. OVERVIEW

Behind the leadership of Secretary of Defense Donald H. Rumsfeld, the U.S. military entered a state of transformation towards network-centric warfare designed to "ensure U.S. forces continue to operate from a position of overwhelming military advantage in support of strategic objectives."[2] Although many enemies of the United States cannot compete in the industrial arena, some may possess the same level of expertise in the information age arena. Thus, as the United States has experienced several times throughout its history, many of our adversaries choose to engage us asymmetrically. Network-centric warfare is a concept that embodies taking advantage of the information age of today to allow U.S. forces to leverage Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) capabilities in defeating future enemies, regardless of their choice of resistance. Another advantage advertised by the implementation of network-centric warfare is a force "defined less by size and more by mobility and swiftness, one that is easier to deploy and sustain, one that relies more heavily on stealth, precision weaponry, and information technologies."[3] Leveraging the information age to do more with less is beneficial in

1 Bernard B. Fall, Winter 1998, http://www.maxwell.af.mil/au/awc/awcgate/navy/art5-w98.htm, last accessed on 7 June 2008.

2 United States Department of Defense, *Transformation Planning Guidance*, April 2003, p. 4.

3 President George W. Bush, Whitehouse Website, May 2001, http://www.whitehouse.gov/infocus/achievement/chap2.html, last accessed on 13 December 2007.

many aspects of modern warfare, but unfortunately, it can be detrimental with respect to the majority effort of current U.S. military forces. This majority effort has been labeled stability operations.

Network-centric warfare's focus on improving efficiency and effectiveness of military operations has proven problematic in the transition out of war operations in both Iraq and Afghanistan. In both operational areas, a major factor that aided U.S. forces in achieving their objectives quickly and effectively was their unmatched technological networking on the battlefield. However, when the smoke cleared, there were inadequate troop levels to penetrate the social network, which is essential for properly executing stability operations. A recurring fact that many nations have learned throughout history is "the decisive battle is for the people's minds."[4] The Department of Defense (DoD) now acknowledges this crucial point and has dictated that stability operations

> . . . shall be given priority comparable to combat operations and be explicitly addressed and integrated across all DoD activities including doctrine, organizations, training, education, exercises, materiel, leadership, personnel, facilities, and planning.[5]

The current transformation of military doctrine is shifting from explicit focus on technological networking to the addition of social networking. This is a necessary transition, as insurgencies will most assuredly be extremely well networked in the social realm of their respective countries.

Stability operations are complex in nature, definition, and execution. Many people use the terms peace operations, nation-building, and stability operations interchangeably. Although there is a relationship amongst these operations, it is imperative to understand the definition of stability operations for the context of this research. The U.S. Army and Marine Corps define stability operations as:

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4 Headquarters, Department of the Army, FM-3-24, *Counterinsurgency*, December 2006, p. 1-27.

5 United States Department of Defense, Department of Defense Directive (DoDD) 3000.05, "Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations," 28 November 2005, p. 2.

> An overarching term encompassing various military missions, tasks, and activities conducted outside the United States in coordination with other instruments of national power to maintain or reestablish a safe and secure environment, provide essential governmental services, emergency infrastructure reconstruction, and humanitarian relief.[6]

We can see from this definition that stability operations encompass a myriad of diverse missions. This research considers peace operations, nation-building, counterterrorism, and counterinsurgency (COIN) operations all subsets of stability operations. However, it is also understood that none of the listed operations can be successfully executed individually without consideration of the others. More importantly, it is essential to understand that these operations are not only dependent upon one another, but also on outside influences such as foreign nations, insurgencies, terrorism, and the civilian populace, to list but a few. Together, the actions and interactions of these groups formulate a complex adaptive system, which have proven difficult, if not impossible, to effectively and efficiently model. This research focuses on the exploration for effective modeling methodologies that capture these complex interactions.

B. BACKGROUND AND MOTIVATION

Civilian human behavior representation (HBR) is an essential element in representing political, military, economic, social, infrastructure, and information (PMESII) aspects of an operational environment undergoing stability operations, and unfortunately, is the least understood. Current military organizational and societal modeling methods are "lacking for complex, dynamic, self-organizing, and adaptive systems in general, and modeling human behavior is particularly problematic."[7] As well, data collection, knowledge acquisition, and behavior representation methods for organizational and societal models are inadequate at best.

6 Headquarters, Department of the Army, FM-3-24, *Counterinsurgency*, December 2006, p. 2-5.

7 United States Department of Defense, Modeling & Simulation Steering Committee (M&SSC), DRAFT, "Modeling and Simulation Steering Committee Common and Cross-Cutting Business Plan," 1 November 2006, p. 39.

The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) designated the Modeling and Simulation Coordination Office (M&S CO) as the focal point for the coordination of all matters related to DoD Modeling and Simulation (M&S).[8] One area of responsibility for M&S CO is to facilitate the development and implementation of Community M&S Business Plans and the Common and Cross-cutting M&S Business Plan.[9]

The Common and Cross-cutting M&S Business Plan is designed "as a guide to implement and promulgate common and cross-cutting tools, data, services, and practices that support the Secretary of Defense (SECDEF) priorities."[10] This plan also identifies current M&S gaps that are believed to be negatively affecting the effective and efficient use of M&S throughout DoD. Table 1 illustrates these M&S gaps, categorized within three major sectors. This research is sponsored by U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) Monterey, California, and supports the Common and Cross-cutting M&S Business Plan by addressing some of the listed HBR M&S gaps. The specific M&S HBR gaps being examined by TRAC Monterey, and various other participating organizations, are listed in Table 2.

[8] United States Department of Defense, Department of Defense Directive (DoDD) 5000.59, "DoD Modeling and Simulation (M&S) Management," 8 August 2007, p. 2.

[9] United States Department of Defense, "Fiscal Year (FY) 2007 Budget Estimates, Research, Development, Test, and Evaluation (RDT&E)," *Defense-Wide*, Volume 3, February 2007, www.dtic.mil/descriptivesum/Y2008/OSD/0603832D8Z.pdf, last accessed on 15 December 2007, p. 3.

[10] United States Department of Defense, Modeling & Simulation Steering Committee (M&SSC) DRAFT," Modeling and Simulation Steering Committee Common and Cross-Cutting Business Plan," 1 November 2006, p. 1.

M&S Gaps		
M&S Technology	**Practices**	**Representations**
Simulation Interoperability	Corporate-level M&S Management and Governance	Human Behavior
Component-based Models and Simulations	Activity-level Model and Simulation Planning and Employment	Environment
Application of Computer Game Technology	Model and Simulation Development and Evolution	Logistics
Resource Discovery and Access	Requirements Definition and Management	Infrastructure
Data Mediation	Conceptual Modeling	Systems, Systems of Systems, and Families of Systems
Visualization Tools	Verification, Validation, and Accreditation	Weapons of Mass Destruction
M&S Infrastructure	Reuse	Forces and Organizations
	Usability of Models and Simulations	Command and Control
	Standards and Processes	Information Operations Intelligence
	Security	
	Workforce Development	
	Communication and Collaboration	

Table 1. M&S Gap Taxonomy (After).[11]

11 United States Department of Defense, Modeling & Simulation Steering Committee (M&SSC), DRAFT, "Modeling and Simulation Steering Committee Common and Cross-Cutting Business Plan," 1 November 2006, p. 4.

Identifier	Description
G-HBR-1	Requirements for synthetic human entities are lacking. These requirements must span blue, red, and gray; must address cultural influences where appropriate; and must be sensitive to the objectives of the exercise/event where they will be employed.
G-HBR-3	Requirements for organizational and societal models are lacking. These requirements must span blue, red, and gray; must address cultural influences, nontraditional warfare, and PMESII aspects where appropriate; and must be sensitive to the objectives of the exercise/event where they will be employed.
G-HBR-4	Data collection, knowledge acquisition, and behavior representation methods for organizational and societal models are immature, inadequate, and in some cases, nonexistent.

Table 2. Identified Human Behavior Representation M&S Gaps (From).[12]

TRAC Monterey's desired deliverables for their Representing Urban Cultural Geography (RUCG) project are threefold. First is a documented methodology to represent civilian populations and their behaviors in urban stability operations. Second is a modeling framework for cultures and societies in the context of nontraditional warfare, as well as the behaviors of the entities making up these populations. Third is an implementation of this modeling framework into a stand-alone simulation tool. This simulation tool must be able to model human behaviors influenced by cultural aspects in stability operations. This research is intended to support TRAC Monterey's RUCG project objectives and deliverables by taking an analytic social theory model suite developed by the RUCG project team to satisfy the first objective, and build within a single modeling environment, a detailed modeling framework that effectively captures its essence. This modeling framework will provide future capability to explore the complex world of HBR, or more specifically with respect to the RUCG project team, of urban cultural geography undergoing stability operations.

12 United States Department of Defense, Modeling & Simulation Steering Committee (M&SSC), DRAFT, "Modeling and Simulation Steering Committee Common and Cross-Cutting Business Plan," 1 November 2006, p. 40.

C. RESEARCH QUESTIONS

The overarching objective for this thesis is to investigate effective modeling methodologies capable of implementing an analytic social theory model suite into a stand-alone simulation tool. This analytic social theory model suite was designed by the RUCG project team to capture HBR with respect to a civilian population undergoing stability operations within an irregular warfare (IW) environment. The various aspects and complex nature of this environment are extremely difficult to model, and subsequently, to analyze. The successful construction of a model within a single simulation tool will provide a capability to explore complex adaptive systems such as this one.

While this research is by no means exhaustive with respect to the overall RUCG project objectives and deliverables, the following research was conducted and questions addressed:

- Can a representative modeling framework for the RUCG analytic social theory model suite be implemented with a stand-alone simulation tool?
- Provide detailed documentation of all successful and unsuccessful modeling methodology mappings, as well as recommendations of enhancements with respect to the simulation tool of choice.

Mappings refer to the simulation tool functionality required to link the desired theory behind the model suite into the simulation tool itself. All knowledge gains are being shared with TRAC Monterey's Multi-Agent System (MAS) model development being conducted in parallel.

D. BENEFITS OF THE STUDY

From a global perspective, this study supports DoD initiatives developed to provide consolidated efforts and improvements to M&S throughout DoD. Ideally, it may indirectly contribute to military doctrine concerning stability operations, such as those currently being conducted in Afghanistan and Iraq, by providing a modeling framework capable of capturing complex interactions of this nature. As previously stated, the battles currently being fought by U.S. forces in these countries are for the minds of the indigenous civilian populace. It is not enough for our military to be only technologically networked, they must be socially networked as well. The current U.S. Counterinsurgency (COIN) manual states "if military forces remain in their compounds, they lose touch with the people, appear to be running scared, and cede the initiative to the insurgents."[13] Any knowledge acquisition that better prepares our troops for stability operations execution will be extremely valuable not only to the troops themselves, but also to the United States in general. The prolonged operations and high deployment rates that U.S. troops are currently experiencing produce a negative impact on survivability, morale, retention rates, and recruitment.[14] This research may open the door for insight acquisition concerning the integral factors that affect a civilian populace during stability operations. This, in turn, may influence doctrinal shifts providing positive impacts on mission execution and timeliness.

From a local perspective, this study directly contributes to TRAC Monterey's objectives, focusing on knowledge acquisition and the development of social theory algorithms applicable to a community-wide range of M&S systems. Innovative modeling methodologies for HBR are explored and evaluated for inclusion into a modeling framework within a simulation tool. This simulation tool is examined as a stand-alone tool for representing the complex social interactions, networks, and events that influence the behaviors and attitudes of a civilian populace. The documented methodology necessary to build this framework enables future construction of models capable of generating data for in-depth analyses of complex interactions related to HBR. At a minimum, this research helps close the HBR M&S gaps listed in Table 2.

E. METHODOLOGY

This research was conducted in a parallel effort with another NPS student, CDR Thorsten Seitz of the German Navy. Another perspective on these research efforts

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13Headquarters, Department of the Army, FM-3-24, *Counterinsurgency*, December 2006, p. 1-27.

14 Congressional Research Service (CRS) Issue Brief for Congress, "Peacekeeping and Related Stability Operations: Issues of U.S. Military Involvement," updated 18 May 2006, www.fas.org/sgp/crs/natsec/IB94040.pdf, p. 13, last accessed on 15 Dec 2007.

can be obtained by reviewing CDR Seitz's thesis.[15] His research efforts focus more on the social networking aspect of our modeling efforts; however, we provide these summary conclusions and offer additional insights gleaned from them.

The first phase of this study involves understanding the characteristics of the RUCG team's analytic social theory model suite. This model suite is composed of three analytic models: an attitudinal effect model, a social network model, and an economic model of insurrection. The algorithms within these models were derived from background research in the fields of sociology, economics, and international relations. We then determine a methodology for mapping the characteristics of these models into a stand-alone simulation tool. The stand-alone tool chosen for this research is Pythagoras 2.0.0. Reasoning for this choice is provided in Chapter II.

The mappings of the social theory model suite into the Pythagoras 2.0.0 modeling environment are evaluated and documented, and limitations and recommendations for improvements are provided. The culmination of this research provides a solid modeling framework that can be utilized for future HBR model constructions. These models will be capable of representing a civilian populace undergoing stability operations and ultimately provide a platform for exploratory analysis of these complex situations. An example scenario is utilized to implement and test various modeling methodologies. As such, the model construction for this research remains abstract in order to allow us to focus on the methodologies necessary to effectively implement the social theory model suite, without having to explicitly model the physical layout of a particular geographic region. The desired end state for our abstract model is one that, with the implementation of recommended capability additions to Pythagoras 2.0.0, can be utilized to explore the complex interactions of a civilian populace undergoing stability operations via high-performance computing assets supporting a data-farming process. Data farming is defined by the Marine Corps Warfighting Laboratory's (MCWL) Project Albert as:

[15] CDR Thorsten Seitz, German Navy, "Representing Urban Cultural Geographies in Stability Operations, Analysis of a Social Network Representation in Pythagoras," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2008.

> A method to address decision maker’s questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options.[16]

This process enables analysts to conduct thousands of computational experiments on their models, while simultaneously manipulating several variables of interest in order to generate and analyze large quantities of data.

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[16] Project Albert Website, http://www.projectalbert.org/, last accessed on 17 December 2007.

II. RUCG ANALYTIC SOCIAL THEORY MODEL SUITE

> Human behavior flows from three main sources: desire, emotion, and knowledge.
>
> –Plato

A. INTRODUCTION

Chapter II begins with a discussion on the reasoning behind the Pythagoras 2.0.0 modeling environment chosen as our simulation tool. This justification is followed by summary discussions of the three analytic models within the RUCG social theory model suite that we attempted to implement into the Pythagoras 2.0.0 modeling environment. Lastly, we provide brief discussions concerning assumptions utilized within each model, and point out areas where we tried to relax these assumptions during our modeling methodology exploratory research.

B. PYTHAGORAS 2.0.0 MODELING ENVIRONMENT

Pythagoras is an agent based model (ABM) developed by the MCWL Project Albert team. Project Albert was an international research and development effort focusing on developing an ABM suite capable of running on High Performance Computing (HPC) clusters in order to reap the benefits offered by data farming.[17] The continuing work started by Project Albert is currently being managed by the Naval Postgraduate School (NPS) Simulation, Experiments, and Efficient Designs (SEED) Center in Monterey, California.[18] Pythagoras is a government-owned and open source ABM written in the JAVA computer programming language, making it platform independent. The maintenance and upgrades for Pythagoras are contracted to Northrop Grumman.

[17] Information on Project Albert can be accessed at http://www.projectalbert.org/, last accessed on 27 February 2008.

[18] Information on the NPS SEED Center can be accessed at http://harvest.nps.edu/, last accessed on 27 February 2008.

1. Why Pythagoras?

Many combat models in existence today focus primarily on the physical characteristics of combat. Pythagoras is a time step ABM designed to provide modelers with the ability to investigate the nonphysical characteristics of combat as well. The previous version of Pythagoras, version 1.10.5, is currently being upgraded to version 2.0.0 in order to further develop these nonphysical modeling capabilities, or intangibles. It is important to note that the version 2.0.0 upgrade is not limited to intangibles and abstract modifications only; however, it is the primary focus of the upgrade. Our research was conducted in conjunction with the development of the Pythagoras 2.0.0 upgrade, and played an integral part in debugging logic code and in implementation of specific capabilities with respect to modeling human behavior with the Pythagoras simulation tool. As expected, this concurrent work had a negative impact on our research timeline. We ended up creating our model with Version 19 of Pythagoras 2.0.0, and were continually submitting requests for modifications believed necessary to accomplish our RUCG model suite implementations. On a positive note, the relationship between the military and Northrop Grumman has been extremely solid. Any bugs reported were quickly fixed and recommendations on code changes were always welcome and sometimes implemented. This is a unique relationship between modelers and developers that provides flexibility to the modeler and adds strength to the model being built and the simulation tool used to do so. However, the strain placed on timelines can be detrimental to the modeler's research efforts.

The Pythagoras 2.0.0 user's manual offers Figure 1 as an overview of what the Pythagoras modeling environment is designed to capture with regard to a combat environment.[19] The primary focus of this research lies in the human factors portion of Figure 1. The listed intangibles corresponding to the human factors portion are merely generalizations concerning soldiers' experiences in combat. These are easily leveraged to represent the intangible experiences of a civilian populace within an IW environment as

[19] Northrop Grumman Space & Mission Systems Corp., *Pythagoras User Manual Version 2.0*, Draft 2007, p. 1-1.

well. The multitudes of intangibles that can be modeled in the human factors realm are limited only by the modeler's imagination. This modeling flexibility within the human factors portion is an extremely attractive characteristic of Pythagoras 2.0.0. This flexibility brings to the fight the ability to explore for possible complex interactions, or with respect to our research, the ability to search for emergent behaviors within a civilian populace resulting from actions targeting their beliefs and issues structures. Hence, Pythagoras 2.0.0 was chosen by TRAC Monterey as the simulation tool to be used for our research efforts. Once again, these efforts are focused on the development of a modeling framework for the RUCG analytic social theory model suite with a stand-alone simulation tool.

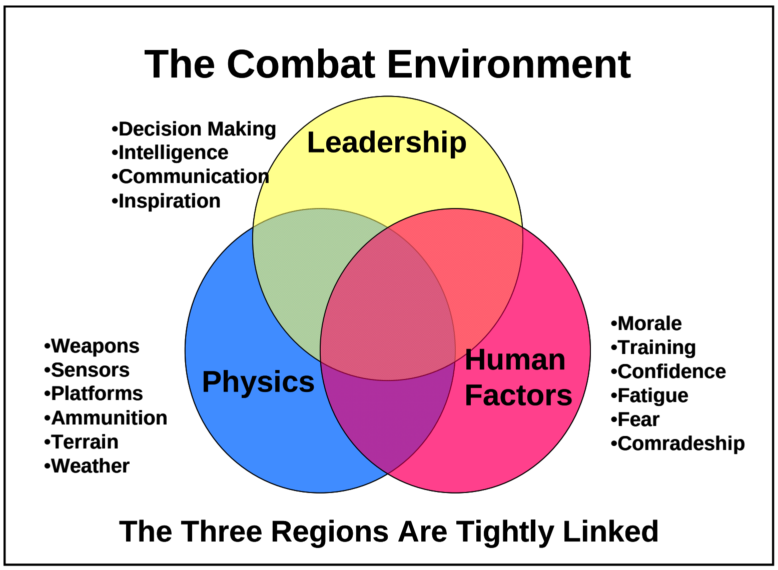

Figure 1. Combat Environment [Best viewed in color] (From).[20]

C. RUCG PROJECT TEAM SOCIAL THEORY MODEL SUITE

One goal of this research was to evaluate the human behavior modeling capabilities within Pythagoras 2.0.0 by attempting to map three analytic social theory models into it. These three models are an attitudinal effect model, a social network model, and an economic insurrection model. Each model is briefly summarized in this

20 Northrop Grumman Space & Mission Systems Corp., *Pythagoras User Manual Version 2.0*, 2007, p. 1-1.

section. The details of these mappings are discussed in Chapter III, along with assumptions utilized, limitations observed, and recommendations for Pythagoras 2.0.0 modifications.

1. Attitudinal Effect Model

The working paper describing this model is provided in Appendix A.[21]

a. Synopsis

An essential aspect of warfare is the battle for the support of the civilian populace. This model quantifies attitudinal change within a civilian populace due to actions taken by designated actors, how the population perceives these actions, the innate attitudes of the subpopulations that the civilian populace is composed of, and the effect of inter-subpopulation influences.

The civilian populace is comprised of subpopulations that are acted upon by various actors. The individual subpopulations are considered homogeneous groups and do not execute actions themselves. A crucial characteristic of this model is the idea of perception driving attitude. Each subpopulation perceives the actions experienced as either good or bad. Levels of goodness and badness are not currently implemented in this model, meaning that differential magnitudes concerning active actions were not explored in the analysis provided. As well, each action experienced does not necessarily induce permanent attitudinal change. Action affects are considered either active or inactive. Active actions, meaning they are influencing subpopulation attitude, last for certain durations. Once active action durations elapse, the actions become inactive and the resultant attitudinal changes are forgotten. The concept of active or inactive actions attempts to capture the various impacts actions may have on different subpopulations' attitudes. It should be stated that this model does not consider distributed memory loss. The total effect of an active action is immediately forgotten and does not gradually decay in accordance with any kind of distribution. Also, because each subpopulation is

21 Patricia A. Jacobs, Donald P. Gaver, Moshe Kress, and Roberto Szechtman, "A Model for the Effect of Host Nation/Insurgency Operations on a Population," Working Paper, Naval Postgraduate School, Monterey, CA, 7 November 2007, pp. 1-16.

considered homogeneous, it is also assumed that each recipient subpopulation responds simultaneously to, and is equally affected by, actions experienced.

The specific model presented focuses on only one subpopulation and two actors: a Host Nation (HN) and an Insurgency. This model assumes that the subpopulation either supports HN or the Insurgency, with no option for maintaining a neutral stance. The attitudinal position towards HN by the subpopulation at a given period in time is dependent upon its respective innate attitude and the active influence introduced into it through active actor actions and social interactions. However, with only one subpopulation, the social interaction influence is not a factor. Again, the subpopulations' attitudinal stances are fought for by competing outside actors. Hence, it is imperative we be able to investigate the subpopulation attitudinal shifts away from their initial positions. Figure 2 is a simplified summary equation intended to portray the recommended way to track attitudinal changes experienced by a subpopulation due to influence from actors and from other subpopulations during time period (t, t+h].

Attitude towards HN at time "t+h"due to active actions	=	Attitude towards HN at time "t" due to active actions		
	+	Mean attitude change due to active HN actions perceived as good during (t , t+h]	–	Mean attitude change due to active HN actions perceived as bad during (t , t+h]
	–	Mean attitude change due to active Insurgency actions perceived as good during (t , t+h]	+	Mean attitude change due to active Insurgency actions perceived as bad during (t , t+h]
	+/–	Mean attitude change due to influence of others		

Figure 2. Summary equation for subpopulation attitudinal change.

The last term of the equation in Figure 2 refers to the influence of others. This influence is representative of social influence on one subpopulation from another subpopulation. This model does provide a function based on subpopulation sizes and initial attitude differentials to capture outside influence. However, we utilize a separate social influence model described in Section III.E as an alternative for capturing this influence. The mean numbers of active actor actions perceived as good or bad in Figure 2 are dependent on the rates at which actors initiate actions, the probabilities these actions are perceived as good or bad, and the mean times the respective actions remain active. With this, the magnitudes of the respective actions are combined with the mean numbers of active actions to determine mean attitudinal change.

Lastly, several numerical examples, with corresponding graphic outputs, are included in this paper.[22] From these examples, the authors offer the following insight:

> These simple models suggest the changes in subpopulation attitude is a nonlinear function of the rate at which actions occur; the rate at which actions affect the subpopulation attitude; the mean time an action continues to influence attitudes; and the basic attitude the subpopulation has towards the actors.[23]

b. Comments

This model provides a simplified approach for monitoring attitudinal change within a civilian population. There are a few broad assumptions and inherent limitations utilized for mathematical tractability that we try to relax within our model in an effort to make it a bit more robust. First, we introduce more than one subpopulation and more than two actors. This allows us to explore the effects of social influence within the civilian populace as well. Second, although the subpopulations are initially homogeneous, they do not respond simultaneously, nor are they equally affected by, actor

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22 Patricia A. Jacobs, Donald P. Gaver, Moshe Kress, and Roberto Szechtman, "A Model for the Effect of Host Nation/Insurgency Operations on a Population," Working Paper, Naval Postgraduate School, Monterey, CA, 7 November 2007, pp. 10-14.

23 Ibid., p. 15.

actions. We also explored distributed memory loss across the subpopulations, however, it was not possible to implement this concept within Pythagoras 2.0.0. Hence, this additional capability was considered, but not implemented, due to limitations within Pythagoras 2.0.0. These attempted modifications are discussed further in Chapter III.D.

2. Social Network Model

The set of notes describing this model is provided in Appendix B.[24]

a. Synopsis

This model is a general and basic social network model that captures influence exchange within a social system. It assumes that inter-subpopulation and intra-subpopulation influences occur on a daily basis. Attitudinal influence on entities within a given network is a function of the issues believed to be important and the relationship between those interacting within the network. For example, one entity may believe that the right to practice religion is the most important issue to be considered by his/her respective governing body, followed by funding for infrastructure improvements and physical security, and lastly, economic security. Another entity may believe the only important issue is economic security. Even though the valued hierarchical issue structures of these entities are not aligned, the relationship between them may be strong and respectful. Hence, their ability to influence one another is still possible. Contrary to this scenario, if various entities' hierarchical issues are completely aligned, but they hate each other, influence exchange is not very likely. Consequently, the magnitude of attitudinal change implemented upon an entity is dependent upon both the hierarchical issue structures of those involved, and the types of relationships between them. Lastly, the model mentions the idea of autocorrelation concerning influence. This concept dictates that if an entity can influence another on one issue, it is likely that it can also inject influence concerning other issues.

[24] David Krackhardt, Notes on Influence Models for Dynamic Settings, The Tepper School of Business, Carnegie Melon University, September 2007.

b. Comments

Although this is a straightforward and basic social network model, it contains an underlying assumption that all entities within the social network act rationally and experience influence exchange in a logically diffusive manner. This may be a strong assumption because our social system of interest is a civilian populace composed of extremely segmented subpopulations existing in an IW environment. Hence, unlikely relationships may be formed due to the myriad of unpredictable events that can occur within an IW environment. As an example, even though two groups share nothing in their basic hierarchical issue structures, and in fact despise each other, an outside event or issue may interject into both hierarchical issue structures as a temporary top priority. Because of this, a temporary relationship may be formed until the status quo is retained. We were forced to make a decision on a question that is continually encountered when attempting to model complex systems: Do the potential gains outweigh the cost in complexity? We determined that although adding the concept of irrational behavior may be more realistic, the potential gains are outweighed by the complexity costs with respect to the necessary changes within Pythagoras 2.0.0. As well, the addition of this capability for enhancement of the social network model may even complicate our quest of flushing out emergent behaviors within our target population. Therefore, the recommendation for additional capability to model irrational behavior was entertained, but not requested.

3. Economic Insurrection Model

The PowerPoint presentation describing this model is provided in Appendix C.[25]

a. Synopsis

This model builds a picture of a sovereign state trying to minimize the probability of an insurrection, while simultaneously maximizing economic security for the constituents. The constituents are those in the civilian populace working as

25 Robert. M. McNab, "A Model of Insurrections," PowerPoint presentation given 5 October 2007 at TRAC-Monterey, CA.

production force laborers, soldiers, or participants in an insurgency. The lowest level of detail concerning constituents is homogeneous family units. These family units respond to the actions of the sovereign state by allocating their time to the production force, soldiering, and/or insurgency economic sectors. The sovereign state obtains feedback concerning their current polices on the constituents and adjusts accordingly to try and minimize the growth of the insurrection and directly manipulate the constituent time allocation to the various economic sectors. Each of the three economic sectors carries its own wage rate, and the state production force and soldiering sectors also suffer taxes. The expected net income for each family is dependent upon the sum of their expected incomes from working in the various economic sectors. These expectations are driven by their perceptions of the probability that the insurrection will be successful. In turn, this perception directly influences the times they decide to allot to working in each economic sector, along with the set wages and tax rates per sector. The probability of a successful insurrection is dependent upon the average time actually allotted by the constituents to soldiering and participation in the insurgency, as well as the technological capabilities of the respective insurgents and soldiering forces. Seven possible scenarios are presented in this presentation discussing initial distributions of average time allocations to the three economic sectors, with example results listed in an accompanying spreadsheet.

b. Comments

The assumption that there is a sovereign state in control of the civilian populace implies that the current governing state is a recognized and dominant force that maintains control over the civilian populace. This is a strong assumption, with respect to nations undergoing stability operations following a state change due to war. The current governing state during stability operations may be neither recognized by all constituents nor dominant. Thus, the governing state's ability to influence its constituents' desired time allocation to the various economic sectors, as well as prevent outside and undesirable influence, may be far from comparable to a sovereign state. In other words, in an IW environment, the determining factors affecting the constituents' time allocations to the economic sectors is not completely under the control of the current governing state.

Therefore, for our modeling purposes, we intend to inject influence on time allocation due to other outside influences, such as foreign nations and terrorist organizations.

We previously discussed the idea of influence exchange through a social network. The economic insurrection model does not consider economic security changes resulting from social network interactions. Our model attempts to add this characteristic to the overall system, both temporally and spatially. This is discussed further in Chapter III.F.

III. MODELING METHODOLOGY

Theory must result in insight and withstand testing.[26]

A. INTRODUCTION

This chapter provides details of our RUCG modeling methodology. We first provide an overview of our example scenario that serves as our foundation for discussion and explanations. Next, we discuss some common characteristics that are inherent to all three RUCG model implementations. The settings listed in this scenario are not actual data collected from a designed data acquisition process. These settings only serve as tools for aid in explanations. We use four specific terms continuously throughout Chapter III: attitudes, colors, issues, and attributes. Attitudes are represented by colors and issues are represented by attributes. We use the terms interchangeably, but endeavor to use color and attributes when referring to Pythagoras mappings, and issues and attitudes when referring to our example scenario. Lastly, we discuss the respective mappings of the RUCG model suite into the Pythagoras modeling environment, list the specific assumptions that accompany these mappings, provide limitations encountered, and offer recommendations for improvement and/or capability. The resultant modeling methodology is intended to provide insight into Pythagoras 2.0.0 HBR capabilities, offer explanations for generic HBR model constructions from the ground up, and give future modelers in this arena cardinal directions for their data collection efforts.

B. EXAMPLE ABSTRACT SCENARIO

1. Overview

This overview provides general explanations of our desired framework. The detailed implementation descriptions of each aspect discussed here are provided later, in

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[26] John H. Miller and Scott E. Page, *Complex Adaptive Systems, An Introduction to Computational Models of Social Life*, Princeton University Press, 2007, p. 63.

the appropriate model mapping sections. Our example scenario consists of a civilian populace comprising two subpopulations and three actors competing for their support. Each subpopulation possesses a general initial attitude towards HN. We categorize four possible population segments that members of each subpopulation are initially distributed: insurgent, production force initially leaning towards the insurgency (PF_ILT_I), production force initially leaning towards HN (PF_ILT_HN), and soldiering. Thus, even though the majority of a particular subpopulation may initially lean towards supporting HN, some members may be participating as soldiers or insurgents, for example. In other words, even though agents may be members of one subpopulation, they may have different attitudes towards the state of the nation based on their own experiences with respect to their hierarchical issue structures.

A hierarchical issue structure refers to the issues that a subpopulation believes important. The actors are representative terrorist organizations, Coalition Forces (CF), and HN governing leadership. The goals of HN/CF and the terrorist organizations are to take actions with respect to the subpopulations' hierarchical issue structures in efforts to influence attitude change towards and away from HN, respectively. Global actions, such as media events, refer to actions that affect the entire civilian populace. Nonglobal actions are actions that directly affect various subsets of the civilian populace; events such as a terrorist attack in a particular neighborhood. The susceptibility to influence concerning each hierarchical issue structure is dependent on the respective strengths of beliefs. There are three representative economic sectors that each agent can profit in: a production force sector, an insurgent sector, and a soldiering sector. A social network exists within the civilian populace. The various networks and the distributions of participation within these networks are based on the respective agents' constantly changing attitude toward HN. Lastly, each time step for our scenario notionally represents one day.

At this point, we would like to clarify the use of the terms "insurgent" and "terrorist." This research does not consider these terms to be synonymous. We consider an insurgency to be a political movement intended to implement change, and terrorism as a physical action. Although terrorism can be used as a weapon by an insurgency, insurgencies do not necessarily do so.

2. Common Characteristics

Several settings within Pythagoras provide the same functionality regardless of the model under discussion. We provide these commonalities up front and then offer the individual mappings required for each analytic model within the RUCG model suite in Sections C, D, and E.

a. Attributes

The first common characteristic for the RUCG model suite mappings into the Pythagoras modeling environment is the use of attributes to represent issues within a respective agent's hierarchical issue structure. Pythagoras 2.0.0 allows each agent to possess ten attributes compared to only three in version 1.10.5. These attributes are used to represent the issues within all subpopulations' hierarchical issue structures.

b. Sidedness

Another common characteristic is the sidedness for each agent. Sidedness represents affiliation in Pythagoras, and is set via three colors: red, green, and blue. Affiliation determines if an agent views another as a unit member, a friend, as neutral, or an enemy. For this research, the only color utilized is blue, and it directly represents the agents' attitudes towards HN. A "Working Agent Pairwise Color Comparison" spreadsheet is provided with each version of Pythagoras to help users determine agent affiliations. The completed spreadsheet utilized for our scenario is provided in Appendix D. A major limitation in Pythagoras, with respect to color and attributes, is the absence of any link between them. This means that even though we can induce actions against up to ten different attributes per agent, the results of these changes do not automatically change agent color. Within the context of our modeling goals, any influence due to perceived actions exerted on agents' hierarchical issue structures do not automatically result in attitudinal shifts. This capability is the backbone of our desired modeling methodology. Therefore, we developed a spreadsheet to determine the appropriate weighted color changes to be applied to agents' attitudes after experiencing influence via attribute changes. It is imperative to understand the desire for this link and the resulting weightings in order to follow the modeling methodologies provided. Hence, we discuss these ideas and provide our spreadsheet converter next.

c. Sidedness Value Interpretation

Once again, color represents attitude towards HN for our modeling efforts, and Figure 3 breaks down the color values and corresponding interpretation with respect to them. A blueness value of 255 represents extreme satisfaction with the HN, while a value of 0 represents complete disdain. The civilian populace is comprised of two subpopulations, each of which may have members distributed within the four population segments displayed in Figure 3. Thus, we initialize agents to appropriate blueness settings within the representative blueness ranges displayed. We refer to these blueness ranges as blueness "bins."

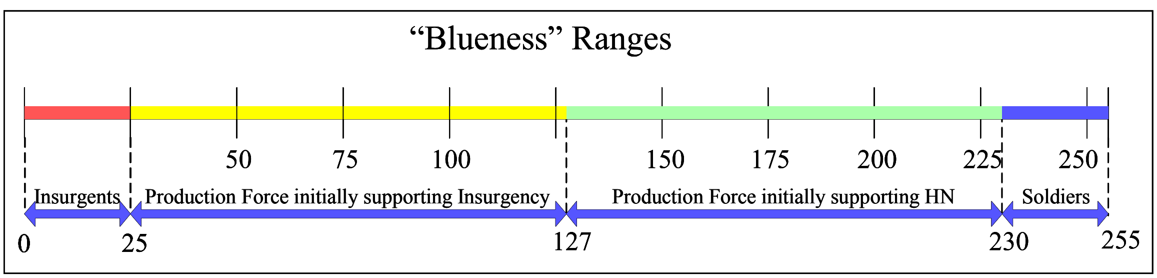


Figure 3. Example scenario color scale representation. [Best viewed in color]

Influential subpopulations and their initial attitudes towards HN are scenario-dependent and need to be determined from a designated data collection effort. For our scenario, we chose the midpoints of the production force ranges displayed in Figure 3 for our two subpopulations. These results are graphically displayed in Figure 4. We see that subpopulation 1 (S1) is initially content with the actions of HN and is generally supportive, while subpopulation 2 (S2) is not satisfied, and generally supports the insurgency. As well, Figure 4 captures the idea that even though the S2 majority generally leans towards the insurgency, some members possess attitudinal stances aligned with insurgents, PF_ILT_HN, and soldiers. This is also true for S1, although we did not display this in Figure 4. The vertical bars represent the distribution magnitudes for each subpopulation into the various population segments. Hence, the overall plot represents the distribution of the civilian populace via subpopulations placed in the appropriate population segments for the particular region of interest.

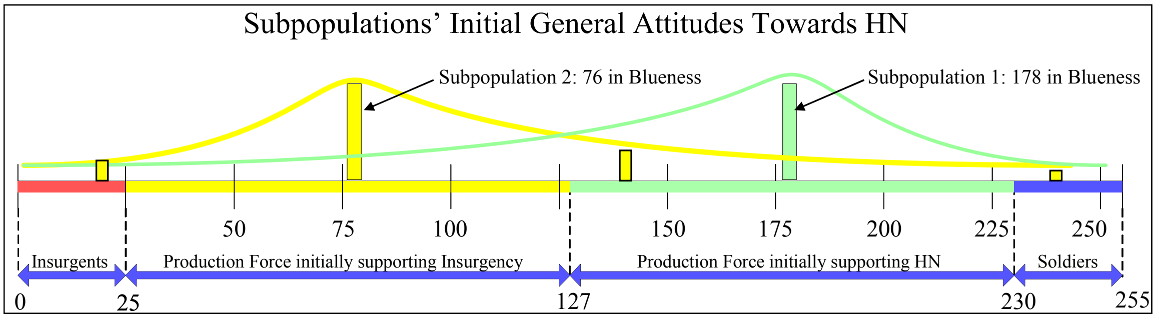


Figure 4. Example scenario subpopulations' initial attitudinal stances. [Best viewed in color]

d. Attribute Change to Color Implementation Method

Once the civilian population under consideration has been properly distributed into population segments, it is necessary to link the effective actions taken against the various subpopulations' hierarchical issue structures to attitude change along the blueness scale displayed in Figures 3 and 4. First, we designed the hierarchical issue structures for the chosen representative subpopulations constituting the civilian populace. Normally, this would be driven by a designed data collection effort. For our scenario, we chose to model four issues believed important by both S1 and S2. The issues represented by attributes for S1 and S2 are: religious freedom, infrastructure, physical security, and economic security. Each of these issues is ranked in order of importance for S1 and S2. Based on the importance of each issue per subpopulation, the respective issues are assigned weightings. These weightings, in turn, represent the priorities instantiating the hierarchical issue structures.

We previously stated that there is currently no direct link in the Pythagoras modeling environment between attribute changes and color. As well, the attribute range in Pythagoras is from 0 to 1,000, while the color ranges are from 0 to 255. We approached this problem by using triggers within Pythagoras. Triggers are events that occur during a scenario that allow the modeler to assign alternate behaviors for the respective triggered agents. There are trigger options for all ten attributes. We instantiated trigger sets in Pythagoras to trigger each agent to an alternate behavior when any attribute experiences an increase or decrease of 50 units. This alternate behavior changes triggered agents' color according to the weighted assignments in their respective hierarchical issue structures.

The settings utilized for S1 and S2 are displayed in Tables 3 and 4, respectively. These tables show that S1 and S2 care most about religious freedom, then economic security, followed by infrastructure concerns and physical safety. However, from the weightings listed, we see that they differ on how important each issue is. Nonetheless, for respective 50 unit changes in these attributes due to experienced actions and/or social influences during the course of the simulation, the listed color changes are implemented with triggers. These color changes are also known as "splashes." In Tables 3 and 4, which are constructed using the spreadsheet in Appendix E, we use the predetermined color change per chosen trigger set width and multiply it by the entered weights in order to determine the appropriate color splash per hierarchical issue. As we can see from the right sides of Tables 3 and 4, there are errors introduced by using this method. The fact that every 1 unit change in attribute corresponds to a 0.255 change in color, is a limitation within Pythagoras because attribute and color inputs must be integer values. Unfortunately, this cannot be circumvented without coding changes to Pythagoras. A spreadsheet designed for determining proper color splashes in accordance with determined attribute weightings and desired trigger set widths for up to ten attributes is provided in Appendix E. Users may use this spreadsheet to try and minimize this aspect of attitude representation error by choosing trigger set widths with lesser errors. However, depending on the desired model and accompanying data collection effort, this may not be an option.

Weights	0.5	0.15	0.05	0.3	Actual Color Change Implemented	Proper Color Change Amount	Color Change Conversion Errors (%) per Trigger Set
Issue Name	Religious Freedom	Infrastructure	Physical Security	Economic Security			
Desired Fidelity	Color Change for Attribute 1	Color Change for Attribute 2	Color Change for Attribute 3	Color Change for Attribute 4			
	Priority						
	1	3	4	2			
10	1	0	0	1	2	2.55	21.57
20	3	1	0	2	6	5.10	17.65
30	4	1	0	2	7	7.65	8.50
40	5	2	1	3	11	10.20	7.84
50	6	2	1	4	13	12.75	1.96
60	8	2	1	5	16	15.30	4.58
70	9	3	1	5	18	17.85	0.84
80	10	3	1	6	20	20.40	1.96
90	11	3	1	7	22	22.95	4.14
100	13	4	1	8	26	25.50	1.96

Table 3. Subpopulation 1 hierarchical issue structure color splash magnitudes for tracking fidelity of +/– 50 unit changes in attributes. [Best viewed in color]

Weights	0.7	0.05	0.05	0.2	Actual Color Change Implemented	Proper Color Change Amount	Color Change Conversion Errors (%) per Trigger Set
Issue Name	Religious Freedom	Infrastructure	Physical Security	Economic Security			
Desired Fidelity	Color Change for Attribute 1	Color Change for Attribute 2	Color Change for Attribute 3	Color Change for Attribute 4			
	Priority						
	1	3	4	2			
10	2	0	0	1	3	2.55	17.65
20	4	0	0	1	5	5.10	1.96
30	5	0	0	2	7	7.65	8.50
40	7	1	1	2	11	10.20	7.84
50	9	1	1	3	14	12.75	9.80
60	11	1	1	3	16	15.30	4.58
70	12	1	1	4	18	17.85	0.84
80	14	1	1	4	20	20.40	1.96
90	16	1	1	5	23	22.95	0.22
100	18	1	1	5	25	25.50	1.96

Table 4. Subpopulation 2 hierarchical issue structure color splash magnitudes for tracking fidelity of +/- 50 unit changes in attributes. [Best viewed in color]

e. Vulnerability

There are physical vulnerability, color vulnerability, and attribute vulnerability settings in Pythagoras. Physical vulnerability is not a player in our modeling as the only shooting happening is that of influence; there are no hard kill weapons required for this research. Color vulnerability in not required either, as all attitudinal change stems from actions against attributes. We do splash agents with appropriate weighted color within an alternate behavior side property tab; however, this particular implementation method is not linked to the color vulnerability settings. We focus on the attribute vulnerabilities for this research. The attribute vulnerabilities can be set per attribute, as well as initialized with a desired tolerance. While attributes represent issues in the various hierarchical issue structures of the agents, the vulnerability settings represent the strengths of the beliefs that are the driving force behind them; the difficulty required to exert effective influence.

A limitation associated with attribute vulnerability settings exists due to differences in modeling conventional warfare versus our efforts of modeling attitudinal change within IW. A person's vulnerability to a bullet is the same regardless of whether the shooter is a friend, an enemy, or a neutral party. As such, there is no control in Pythagoras allowing variation of vulnerability settings depending on the relationship between the shooter and the target. However, for our modeling efforts, this is exactly the type of control we would like. As discussed in the social network model synopsis in II.C.2.a, the ability to influence another in our social network is indeed dependent on this relationship. Ideally, we would like to be able to assign vulnerabilities according to the sidedness differentials between those connected in the social network. For example, if you are talking to a friend, the vulnerability would be relatively high, and for an enemy, relatively low, etc. We cannot implement this methodology here, but we will attempt to capture this idea utilizing communications devices, which will be discussed in detail in III.D. Hence, the attribute vulnerability settings for our agents will remain constant throughout the entire simulation. These vulnerabilities will represent the difficulty to influence an agent's individual attributes, regardless of whether the attempted influence is coming from friends, enemies, or neutral parties. The more one believes, the harder it is to influence the issues derived from these beliefs. The idea of affiliation will be instantiated with communication devices. This is discussed in detail in III.D as well.

f. Time Step and Terrain

The extent of abstractness in our modeling efforts forces us to interpret time steps, distance, and speed in a nonstandard manner. Normally, when building scenarios with ABMs, the time step, agent speed, and the physical terrain are directly linked. This is not the case within our modeling methodology. We are not trying to map an actual geographic region into our models. The terrain pieces implemented represent the various economic sectors for the economy. For example, to capture the essence of the economic insurgency model, we have three economic sectors: a production force economic sector, an insurgency economic sector, and a soldiering economic sector. Another way to look at it is these sectors represent where the agents can receive their economic security; by working in the production force, participating in the insurgency, or joining the soldiering forces. Time steps are not linked to speed and distance. The firing rates of the actors are the actual link to our time step. Movement exists only to allow agents the capability to switch between economic sectors. The methodology for movement implementation will be discussed in further detail within the mappings presented for the economic insurrection model in Section E.1.c.

3. Agent Descriptions

a. Overview

These agent descriptions are provided to allow us the ability to utilize accurate screenshots from our model for presentation of our modeling methodology. We continually refer to agents by the names utilized in the scenario for presentation of methodologies for the numerous implementations necessary to capture the entire RUCG model suite. The agents presented here are limited to subpopulation agents and actor agents only. Subpopulation agents represent subsets of the civilian population that are continually targeted by the actor agents. The actor agents are attempting to apply influence on the subpopulation agents in order to win over their attitudinal stances. This section serves as a general reference for these agent names, descriptions, and their designed roles in the overall scenario. However, the in-depth mappings necessary to make these agents perform their designated roles are provided in III.C, III.D, and III.E. As well, several other agents are utilized in this model for various reasons. We present these agents and their purposes as necessary within the specific RUCG model suite methodology mapping discussions.

b. Subpopulation Agents

Our scenario incorporates two different subpopulations: S1 and S2. These subpopulations constitute the civilian populace and are the target of all actors within the scenario. Subpopulations do not take actions. As previously discussed, each subpopulation is initialized to a general initial attitude towards HN. Also, each subpopulation is distributed amongst four population segments. This results in the following subpopulation agents:

- **S1_Insurgents:** S1 members whose attitudinal stance towards HN, which is based on the status of their hierarchical issue structure, is aligned with those participating in the insurgency. They are not participating in the production force and are officially active participants in the insurgency.
- **Subpopulation 1 initially leaning towards the insurgency (S1_ILT_I):** S1 members whose attitudinal stance towards HN, which is based on the status of their hierarchical issue structure, is aligned with those who are generally unhappy with the performance of HN. They are actively participating in the production force.
- **S1_ILT_HN:** S1 members whose attitudinal stance towards which is based on the status of their hierarchical issue structure, is aligned with those who are generally content with the performance of HN. They are actively participating in the production force.
- **S1_Soldiers:** S1 members whose attitudinal stance towards HN, which is based on the status of their hierarchical issue structure, is aligned with those participating in the soldiering force. They are not participating in the production force and are officially active soldiers in support of HN.
- **S1_Leader:** S1 leader whose initial attitudinal stance reflects that of S1. The main difference for the leader agents is that their social network influence capabilities are greater than those of regular members.

The agents for S2 are identical in format and differ only in initialization, as previously discussed.

c. HN Actor Agents

HN agents perform global actions only. Global actions represent such actions as media events, public affairs campaigns, political agendas, etc. As stated in the attitudinal effect model, all actions are perceived as good or bad by the various members of the civilian populace. Also, for global actions only, we can implement instantaneous memory loss after certain periods of time. This concept is discussed in further detail in III.D. The following HN agents are utilized in our scenario:

- **HN Political Machine Perceived Good/Bad (HN_PM_PG/HN_PM_PB):** These agents take global actions against the entire civilian populace in an effort to gain their support.
- **HN_PM_PG_Duration and HN_PM_PB_Duration:** These agents shoot equal and opposite magnitude influence as their respective counterparts above. The calculated firing rates are set to represent memory loss after desired time periods. In other words, the firing rate differentials create the idea of instantaneous memory loss for the targeted agents.

d. CF and Terrorist Actor Agents

CF and terrorist agents execute non-global actions. These agents are tasked with one of two distinct missions: target/protect civilians or target each other. Therefore, the following agents are utilized in our scenario:

- **CF Security Perceived Good/Bad (CF_Security_PG/CF_Security_PB):** These CF agents are tasked with providing security to the civilian population. They will engage enemies, but their desired movements are to stay near civilians unless actively engaged with the enemy. These agents represent regular security patrols.
- **CF Target Terrorists Perceived Good/Bad (CF_TargetTerrorists_PG/CF_TargetTerrorists_PB):** These CF agents are tasked with searching for and destroying known terrorists. Their movement desires are always towards any enemy within their sensor range capabilities. Sensor range capabilities are representative of the level of intelligence provided to the respective agent.
- **Terrorist versus Production Force Perceived Good/Bad (Terrorist_vPF_PG/Terrorist_vPF_PB):** These terrorist agents target civilians in hopes of instilling fear into those not actively participating in the insurgency.
- **Terrorist versus CF Perceived Good/Bad (Terrorist_vCF_PG/Terroris_vCF_PB):** These terrorist agents are tasked with attacking any CF agents within their sensor range capabilities.

C. ATTITUDINAL EFFECT MODEL MAPPINGS INTO THE PYTHAGORAS MODELING ENVIRONMENT

In accordance with the attitudinal effect model synopsis in II.C.1.a, the resultant mappings to capture its essence are provided. Take note of the blue highlights within each figure provided. These highlights capture the tab selections within Pythagoras, as well as anything selected within the tabs. This aids in understanding the examples offered for methodology implementations. Also, some of the figures offered contain layered cutouts from other tabs in Pythagoras to help consolidate pictorial representations of the various mappings presented. These cutouts are highlighted in red.

1. Mappings

a. Initial Attitudinal Stances

The initial attitudinal stances of S1 and S2 represent their current respective attitudes towards HN. Current attitude representation corresponds to the time period just prior to the desired timeframe under investigation. These settings are implemented in Pythagoras by first constructing the desired settings in the "Sidedness" tab and then assigning these various sidedness listings to the proper agent. We use an S1_ILT_HN agent to illustrate this mapping process. Figure 5 shows the construction of a "PF_ILT_HN" sidedness. The blueness value of 178 is the initial attitudinal stance of any agents who are initialized with this sidedness. Thus, for the S1_ILT_HN agents, we attach this sidedness listing, as shown in Figure 6. It is important to remember that these are only initial settings. As the simulation runs and the agents are influenced, these blueness values will change with respect to the scale shown in Figure 4. The sidedness settings for each type of agent in our scenario are listed in Appendix D.

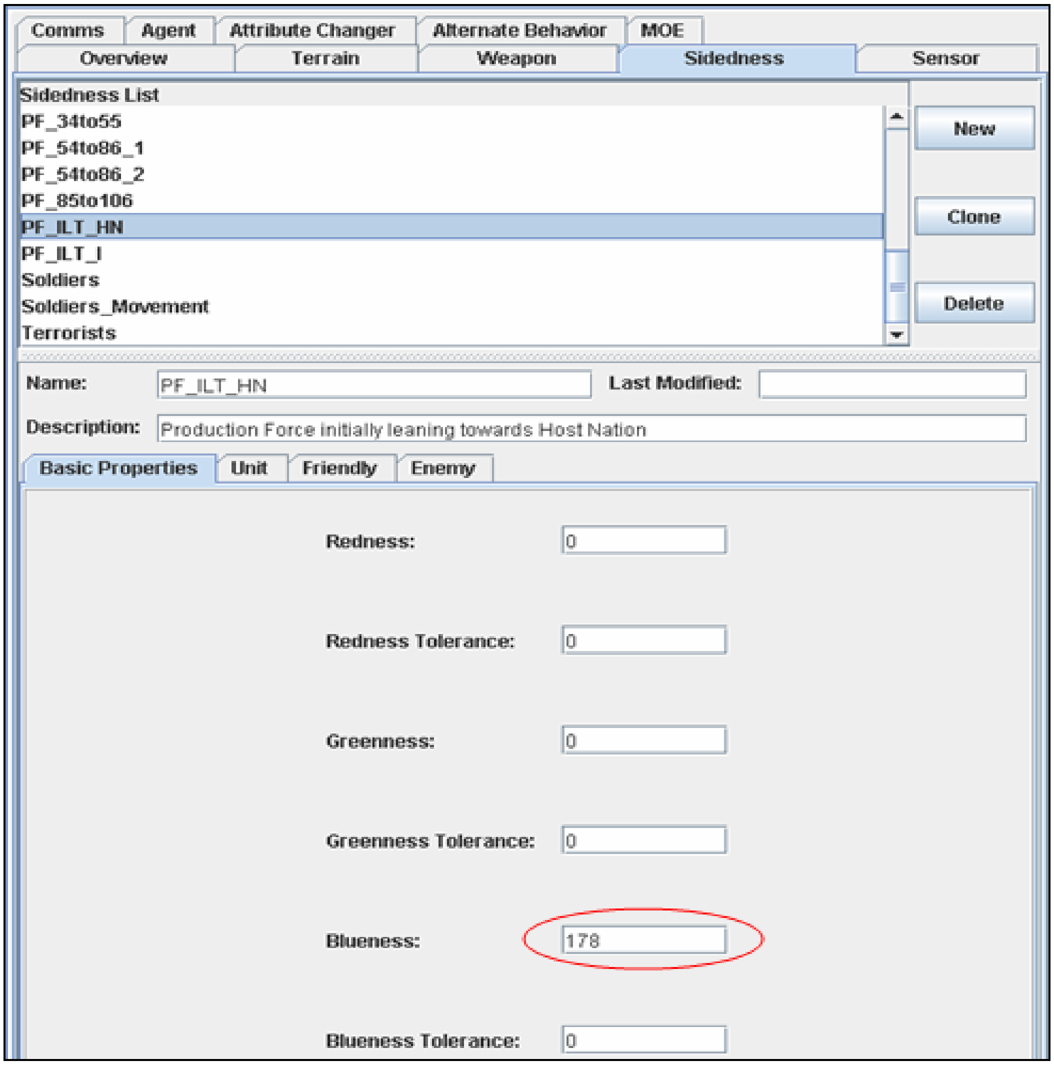


Figure 5. "Sidedness" tab for initial attitude settings (from Pythagoras 2.0.0 Version 19).

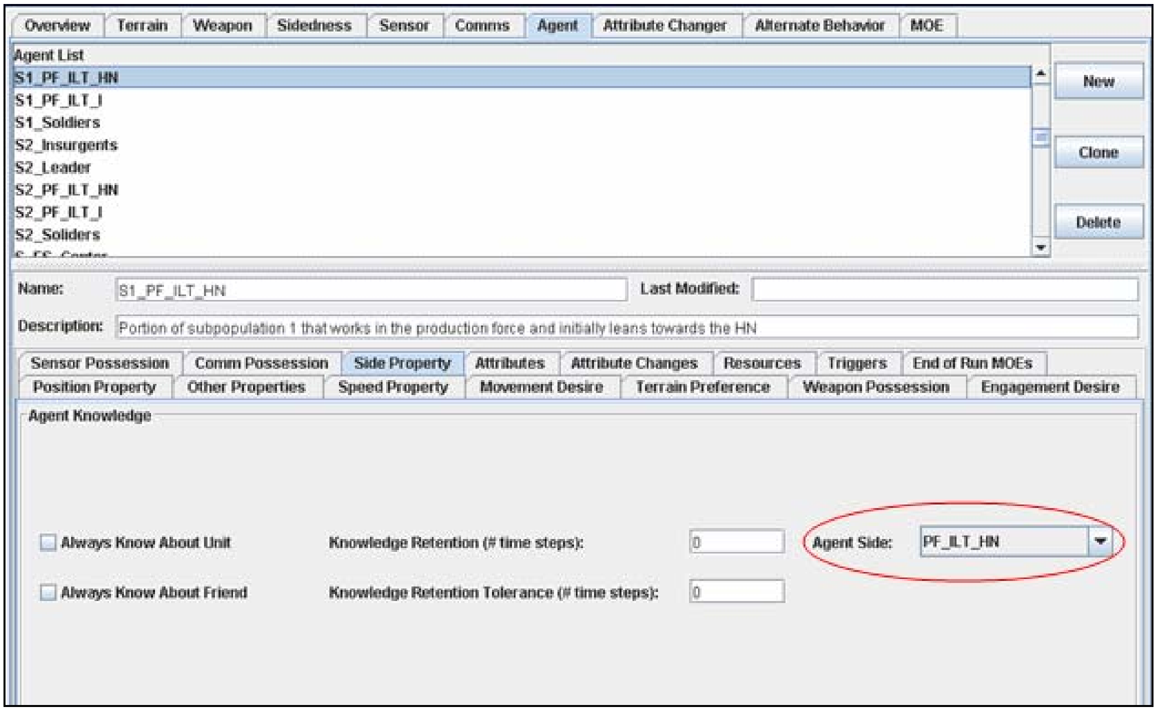


Figure 6. Assigning initial attitudes to representative agents (from Pythagoras 2.0.0 Version 19).

b. Perception of Active Actions

There is no setting in Pythagoras for perception. There are two ways to implement the idea of perception within the model. Each implementation has associated limitations. We utilize separate agents in order to represent actions perceived as good or bad. For example, within our scenario we have terrorist agents that take actions that are perceived as good (Terrorist_vCF_PG), and separate terrorist agents that take actions that are perceived as bad (Terrorist_vCF_PB). Each of these agents carry up to four weapons with associated perceived good and perceived bad attribute changers, respectively. This implies that actions taken by actor agents against others result in correlated influence; meaning if one issue in a hierarchical issue structure is negatively influenced, it is likely that the others are negatively influenced as well. The accuracy of this type of relationship can be argued either way. However, this is in line with the theory discussed in the social network synopsis as well. Also, by utilizing separate agents, we are able to set the approximate probabilities that actions are perceived as good or bad with designed ratios of good agents versus bad agents, along with their respective fire rates. Granted, this is a very loose approximation, but it is the best method we could devise without a direct capability to set these probabilities in Pythagoras.

We also explored a method involving the use of single agents to represent both types of perceived actions. This is possible due to the added capability for agents to carry multiple weapons and engage more than one target per time step. However, we believe the resulting correlations for this particular methodology must be more scripted by the user. By scripting, we are referring to the necessity to monitor self-induced influence dependencies. It will be important to ensure that agents for all possible combinations of perceived good and perceived bad weapons are constructed in the absence of extremely accurate data from which to build these actor agents. As well, an actor agent carrying a perceived good weapon for a particular issue cannot carry a perceived bad weapon for that same issue if the fire rates are equal for both weapons. If an agent is constructed in this manner, the attempted influences will immediately cancel each other out. This method requires more agents to be constructed, a very accurate data collection effort concerning issue relationships, and more scrutiny in their design. Granted, if the detailed data collection effort concerning issue relationships is successfully achieved, the potential for this setup may be superior to the first one discussed. However, at this stage in our methodology search, we believe this method is more dangerous since it requires more assumptions on issue relationships that in actuality, we do not know. Hence, we decided to implement separate agents—perceived good agents and perceived bad agents.

c. Memory Duration

Once again, there is no direct setting in Pythagoras that allows the effect of actions performed to be limited for designated time periods. We are able to instantiate memory for agents only if acted on with global actions; however, this memory loss is instantaneous and not in accordance with any kind of distribution. Remember, global actions refer to actions that simultaneously affect the entire civilian populace. A global action is easily implemented with indirect weapons that can range the entire play box. We utilize paired agents to implement this characteristic.

Figure 7 shows a HN_PM_PG agent carrying a HN_PM_PG weapon. This weapon has an attached attribute changer that increases a successfully targeted agent's religious freedom, infrastructure, and physical security attribute values by five units. The fire rate for this weapon is set to 0.2 per time step. For our scenario, each time step represents one day. Hence, the HN_PM_PG agent fires every five days. The memory implementation is attained by also adding an HN_PM_PG_Duration agent. The HN_PM_PG_Duration agent executes actions of equal and opposite magnitudes at a different rate. The rate differentials represent the desired memory durations for the actions. Although not displayed, the HN_PM_PG_Duration agent weapon has an attached attribute changer that shoots negative five religious freedom, infrastructure, and physical security attribute units. The fire rate is set to 0.08333. This fire rate represents one shot every 14 days. Hence, the HN political machine actions perceived as good, in this case, are remembered for nine days. It is important to point out that these results are deterministic only if the tolerance settings for all the inputs discussed are set to 0.0. With tolerance settings other than 0.0, this simulation provides stochastic results.

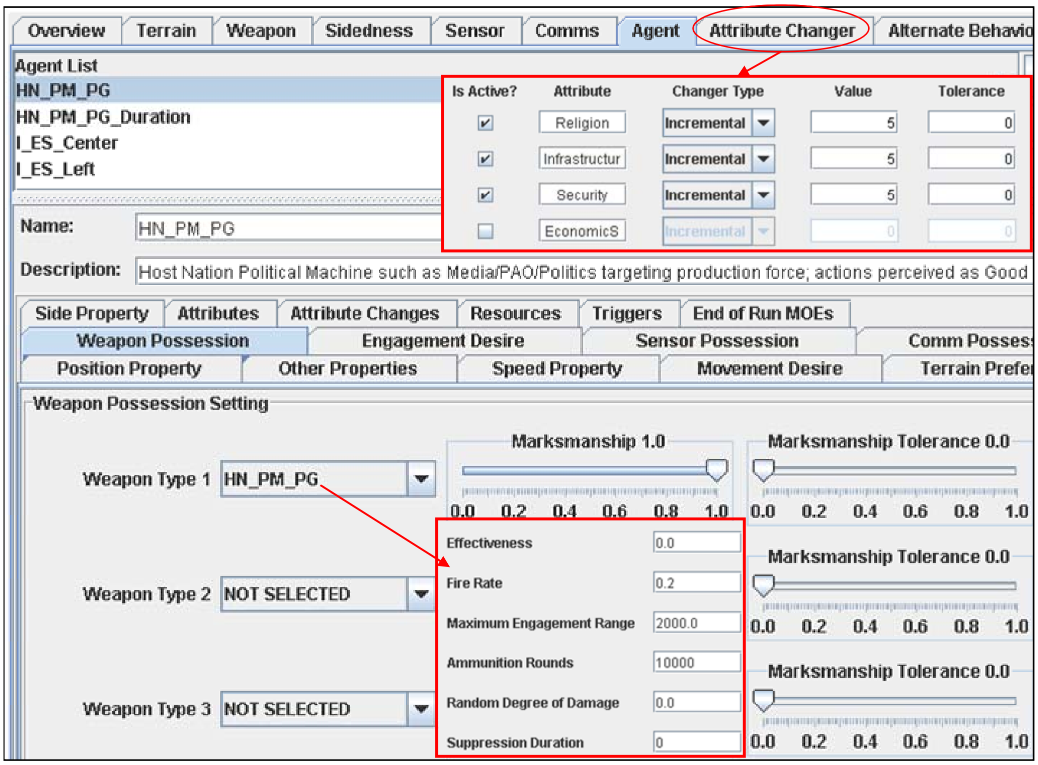


Figure 7. HN_PM_PG actor agent setup for memory loss implementation (from Pythagoras 2.0.0 Version 19).

In summary, every fifth day civilians experience influence from HN, and every 14th day they forget it. This effect in itself is not necessarily absolute, however. Remember, each agent possesses attribute vulnerability settings that affect the amount of influence received. If attribute vulnerability tolerance settings are set to a value other than 0.0, then this effect will not be absolute. Thus, memory loss is quite possible with respect to global actions, but the user should be aware that absolute memory loss implementation is not necessarily occurring when utilizing attribute vulnerability tolerance settings.

Concerning nonglobal actions, accurate memory loss implementation is not possible. Again, nonglobal actions are actor actions against subsets of the civilian populace. Because actor agents and the representative civilian agents are moving during the simulation, there is no manner in which to ensure that actions taken against a particular agent will be removed from that same agent after a specific period of time.

Therefore, we were unable to implement "Duration" agents, and all effective nonglobal actions result in permanent influence. Nonetheless, we still instantiate nonglobal actor agents in pairs of good agents and bad agents. Each of these agents can carry up to ten different weapons. Therefore, it is the option of the user to determine what type of influencer each of these agents will be. An actor agent can carry a separate weapon with an attribute changer for a single issue, or carry several weapons, each capable of applying influence on several issues within the subpopulations' hierarchical issue structures. As well, if an actor agent carries multiple weapons, each one can have a different fire rate. This setup allows for a great deal of flexibility within the model. Figure 8 illustrates an example setup with a Terrorist_vPF_PB agent. This agent carries three separate weapons. The third weapon targets civilian agents' physical security perceptions within their hierarchical issue structures. The fire rate is set to 0.10, representing attempted influence concerning physical security every ten days by this particular actor agent. Since we cannot utilize "Duration" agents to counteract this influence, it is permanent.

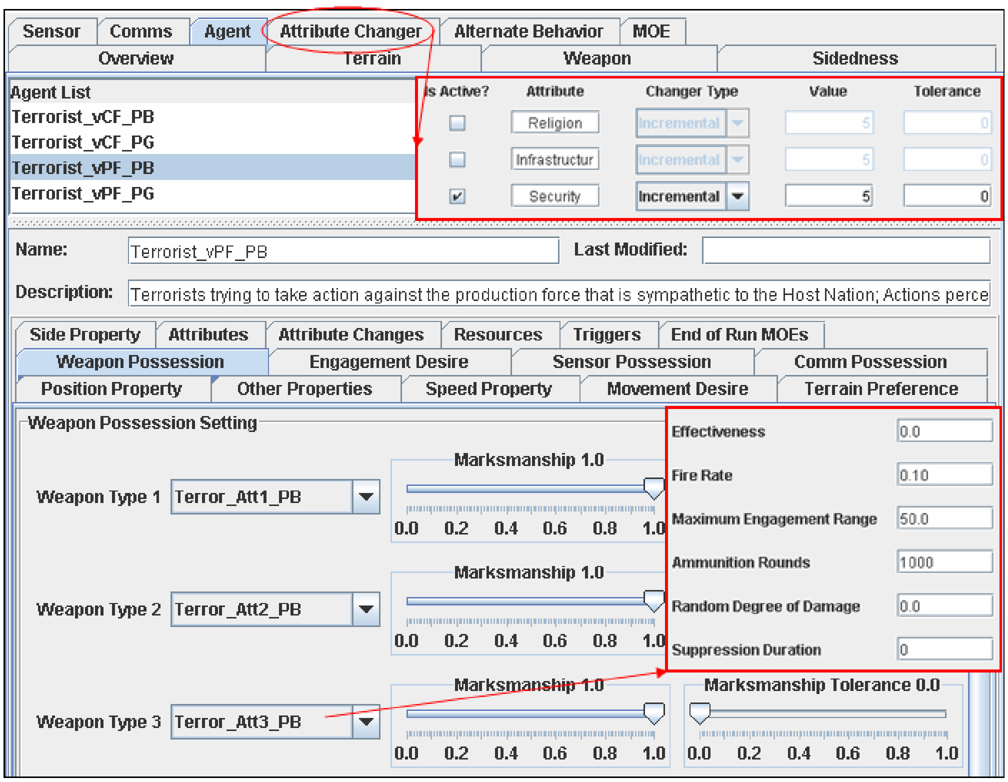


Figure 8. Terrorist_vPF_PB actor agent setup for permanent influence implementation (from Pythagoras 2.0.0 Version 19).

d. Mean Number of Active Actions

This implementation begins with the "Fire Rate" settings in the "Weapon" tab. These settings represent the numbers of actions possible per time step. Active actions perceived as good or bad are implemented with paired agents, as previously discussed. The additive capabilities from the actors' firing rates per weapon, and the number and variety of actor agents instantiated, represent the total number of active actions available during the simulation. This is the number of available or possible actions, because this is a stochastic simulation. The movement and encounters between actors and targeted agents are not scripted in advance. Hence, the true mean numbers of actions taken will be determined after simulation completion by dividing the true number of actions taken by the total number of time steps. As well, due to the flexibility in construction of the various actor agents, the mean number of active actions can be categorized into perceived as good, perceived as bad, global versus nonglobal, and per issue within the various subpopulation hierarchical issue structures.

e. Magnitude of Actions

One change in the Pythagoras 2.0.0 upgrade is the ability to build attribute changers and attach them to weapons. These hybrid weapons shoot attributes just as regular weapons shoot ammunition. The magnitudes of the actions taken are directly represented by the values placed in the attribute changers settings. Examples of attribute changer values are displayed in Figures 7 and 8. These values are representative of the magnitude of influence an actor agent attempts to inject onto the various subpopulations' hierarchical issue structures per action taken. Thus, for our scenario, the fire rate and accompanying magnitudes determine the possible amount of influence per day.

2. Limitations

The first limitation discussed with respect to our attitudinal effect modeling efforts is the capability of representing perception. There is no setting within Pythagoras that allows the user to set a probability that an action is perceived as good or bad.

The second limitation encountered concerned memory implementation. We are limited by Pythagoras in representation of distributed memory loss for global actions and for any type of memory loss for nonglobal actions. As such, we must assume that memory loss due to global actions is instantaneous and that influence resulting from nonglobal actions is permanent.

3. Recommendations

The workarounds utilized for implementation of perception and memory loss are not perfect, but they do capture the ideas fairly well. However, we offer recommendations for possible added capabilities within Pythagoras for HBR modeling efforts. Concerning perception, it would be useful to our modeling efforts to have a perception setting available for each weapon that has an attached attribute changer. This perception setting could be defaulted to represent perceived good actions, and if latched, allow an input from zero to one for a random draw on each action being perceived bad. This would allow for the direct entry of probabilities that actions are perceived good or bad, and greatly reduce the number of actor agents required.

For memory implementation we have to consider the strength of the assumptions forced on us due to the limitations encountered. Remember, we must assume that memory loss due to global actions is instantaneous, while influence resulting from nonglobal actions is permanent. The latter assumption is less concerning than the first. Nonglobal actions can be thought of as personal attacks, which very well may have a permanent effect on an individual's personal hierarchical issue structure. Instantaneous memory loss is more unrealistic. Thus, the ability to implement distributed memory loss for agents would be greatly beneficial, but most likely, will require a great deal of cost in complexity and computer memory.

D. SOCIAL NETWORK MODEL MAPPINGS INTO THE PYTHAGORAS MODELING ENVIRONMENT

In accordance with the social network model synopsis II.C.2.a, the resultant mappings to capture its essence are provided. We refer to networks and the social network throughout our discussions. Networks are the individual network components that the overall social network is comprised from. Another upgrade provided in Pythagoras 2.0.0 is the ability to attach attribute changers to communication devices. This capability was designed specifically to enable the creation of social networks within the Pythagoras modeling environment. Hence, we leveraged this capability as the foundation for our modeling methodology with respect to the social network implementation. The participation distributions and transfers into and out of various networks are accomplished with the use of triggers based on attitudinal shifts. Lastly, these attitudinal shifts are performed via the attribute to color conversion method discussed in III.B.2.d. Once again, we utilize the blue highlights within each figure, along with layered cutouts highlighted in red, to aid us in our pictorial representations of the various mappings presented.

1. Mappings

a. Social Network Construction

There are an extremely large number of different social network possibilities to consider even when dealing with small numbers of people. It is imperative to determine the essential networks within the area of interest that will provide insight concerning the desired end state, while at the same time, not adding an unmanageable amount of complexity to the model. We first determined the number and types of social networking possibilities with respect to S1 and S2 for our abstract area of interest. Once the essential networks were chosen, we switched focus to the strengths of relationships both within and between the subpopulations. Again, the social network we constructed for our scenario is merely an abstract framework and will need to be constructed from background research and a detailed data collection process designed for particular specific modeling efforts.

We determined there were seven essential networks that agents could participate in for our scenario: Insurgent, those partial to an insurgency (PF_ILT_I), those partial to HN (PF_ILT_HN), Soldiering, Neutrals who are on the fence with respect to support for the insurgency or HN, and one network for each of the two subpopulations (S1_Fam and S2_Fam). Figure 9 illustrates six of these seven networks because we show only the S1 family network. Each network is defined by the blueness bins displayed. The subpopulation networks can be thought of as family networks. We assumed that no matter what attitudinal stance an agent ends up taking, there will always be at least some link to family. Hence, the agents do not ever completely exit out of their family network, but their participation levels change in accordance with attitudinal shifts. Also, each family network possesses a leadership aspect that allows the respective subpopulation leaders to impart influence on their members. This leadership influence is only a one-way transfer. Thus, members of the subpopulations listen to their leaders, but do not provide them feedback. For the other networks shown, agents only enter them if their perceptions of satisfaction with respect to HN are aligned with the network perception. Their levels of participation in these networks also change in accordance with their respective attitudinal shifts; however, they can chose to exit these networks completely. These participation levels are represented by the various percentages displayed. Next, we discuss the manner in which we attempted to implement our vision for capturing the social networking aspect of our research.

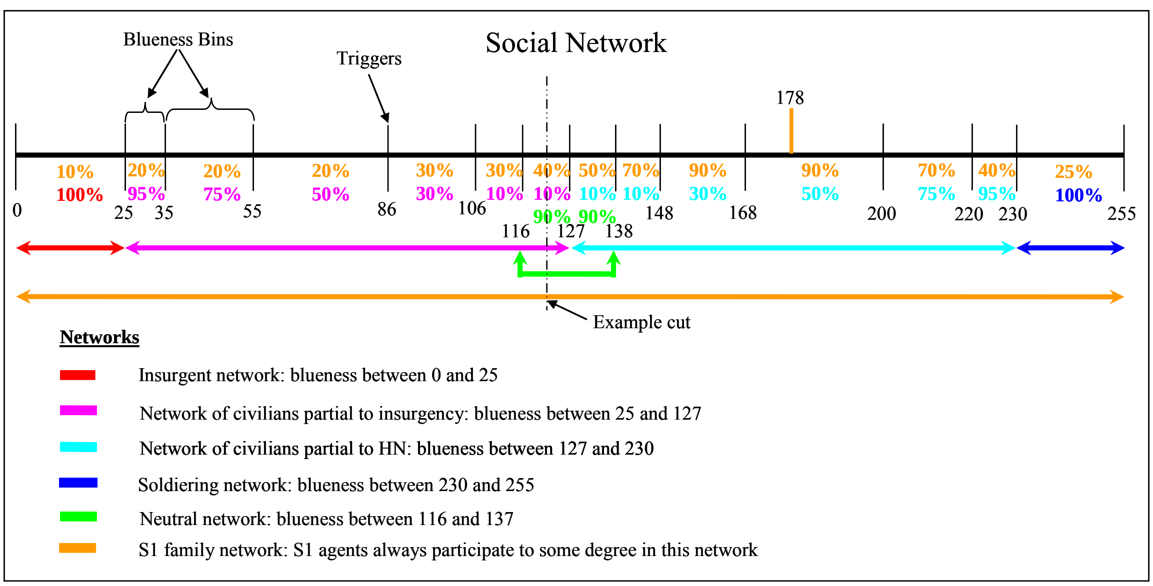


Figure 9. Pictorial representation of social network construct (from Pythagoras 2.0.0 Version 19). [best viewed in color]

b. Networks

Each communication device built within the "Comms" tab represents a different network. Each agent can carry up to ten different communication devices, vice the previous limit of three in version 1.10.5. With the added capability to attach attribute changers to the communications devices, the various communications devices that agents possess directly represent the networks that the agents are active in. Figure 10 illustrates the initial setup for S1. The cutout highlighted in red is a list of nine communication devices built for our scenario. Two of these devices are utilized to allow respective individual leader influence on S1 and S2. The remaining seven devices match the networks portrayed in Figure 9. As we can see from Figure 10, the S1_PF_ILT_HN agents initially participate in their family network as well as the PF_ILT_HN network.

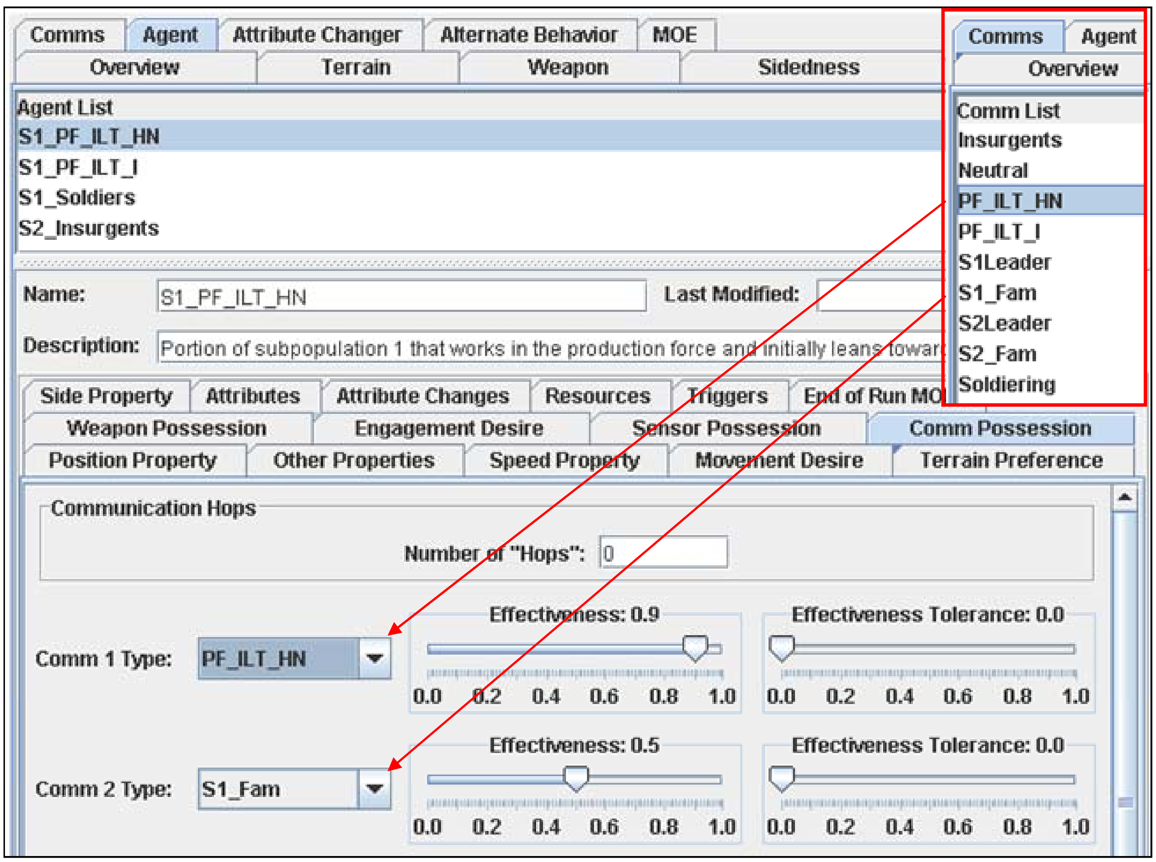


Figure 10. Example of network representation with communication devices (from Pythagoras 2.0.0 Version 19).

Each network is differentiated not only by name, but by channels. Each communication device can operate on three different channels, and each channel can be set to one of 100 settings. Therefore, each device can simultaneously operate on three out of 100 channels. Each of the three channels must be designated as talk only, listen only, or talk and listen. An example for the PF_ILT_HN network is shown in Figure 11. Agents whose attitudinal stances are in agreement with those generally content with HN will enter into this network by receiving the PF_ILT_HN communications device. All members of this network experience influence exchange on channel 5. Table 5 provides the channels, the functionality per channel, and the attached attribute changers for the networks used in our scenario social network construct. Next we discuss the meaning of network participation.

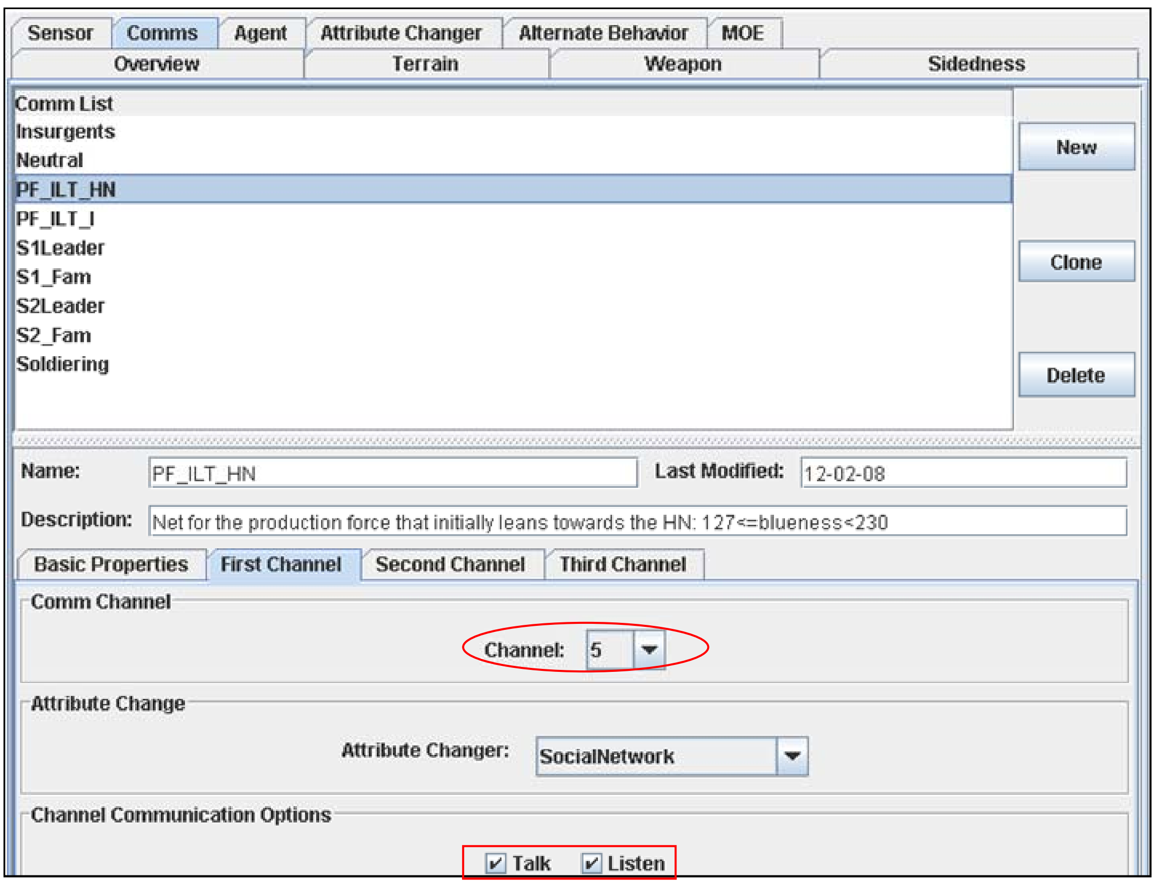


Figure 11. Channel and functionality designation for PF_ILT_HN network (from Pythagoras 2.0.0 Version 19).

Network	Associated Channels	Functionality	Attribute Changer
Insurgent	2	Talk and Listen	SocialNetwork
PF_ILT_I	4	Talk and Listen	SocialNetwork
Neutral	11	Talk and Listen	SocialNetwork
PF_ILT_HN	5	Talk and Listen	SocialNetwork
Soldiering	1	Talk and Listen	SocialNetwork
S1_Fam	3	Talk and Listen	SocialNetwork
	7	Listen Only	None
S2_Fam	6	Talk and Listen	SocialNetwork
	8	Listen Only	None
Note: S1_Fam and S2_Fam networks operate on two channels. Channels 7 and 8 represent the link between S1 and S2 leaders and their respective followers. Further discussion is provided in III.D.1.b.			

Table 5. Summary of social network construct via channels, corresponding channel functionalities, and attached attribute changers.

c. *Network Participation*

Agent participation levels within the different networks are dependent on the attitudinal stances of the agents. We arbitrarily chose the network participation levels and assigned them to the blueness bins illustrated in Figure 9. The number of bins per network equates to the desired fidelity in the model. Looking at the PF_ILT_I network in Figure 9, there are six blueness bins that an agent travels through from entry to exit from the network. Each bin possesses different participation levels for the agents. The attitudinal differentials between the network majority mean attitudinal stance and agents within the network determine the amount of influence that agents can implement or receive in the network. Therefore, the bins encompassing the mean color values per network always possess the highest participation percentages. These illustrated participation level percentages are implemented in Pythagoras via the "Effectiveness" settings in the "Comm Possession" tab, shown in Figure 12. The values entered in the effectiveness settings represent the percent of successful influence transfers from one agent to another. With the effectiveness tolerances set to zero, these percentages represent exact percentages of successful influence transfers; the attribute vulnerability settings have no effect on these transfers.

The example cut line in Figure 9 is provided to help illustrate the process of manipulating participation levels. S1 is initially partial to HN, shown in Figure 9 by a blueness value of 178. Figure 10 illustrates, via the effectiveness settings, that S1 members initially participate in the S1_Fam network at a 90% level and the PF_ILT_HN network at a 50% level. If, during a simulation run, a subset of S1 members is influenced to an attitudinal position within the 116-127 bin, they will be participating in different networks, and at a different level within the S1 family network. The resulting changes are displayed in Figure 12. As we can see, these agents have exited the PF_ILT_HN network altogether, entered the Neutral and PF_ILT_HN networks, and remained in the S1_Fam network. Their participation levels within these networks are 90%, 10%, and 40%, respectively. Next, we provide the role attached attribute changers play in the overall functionality of our social network.

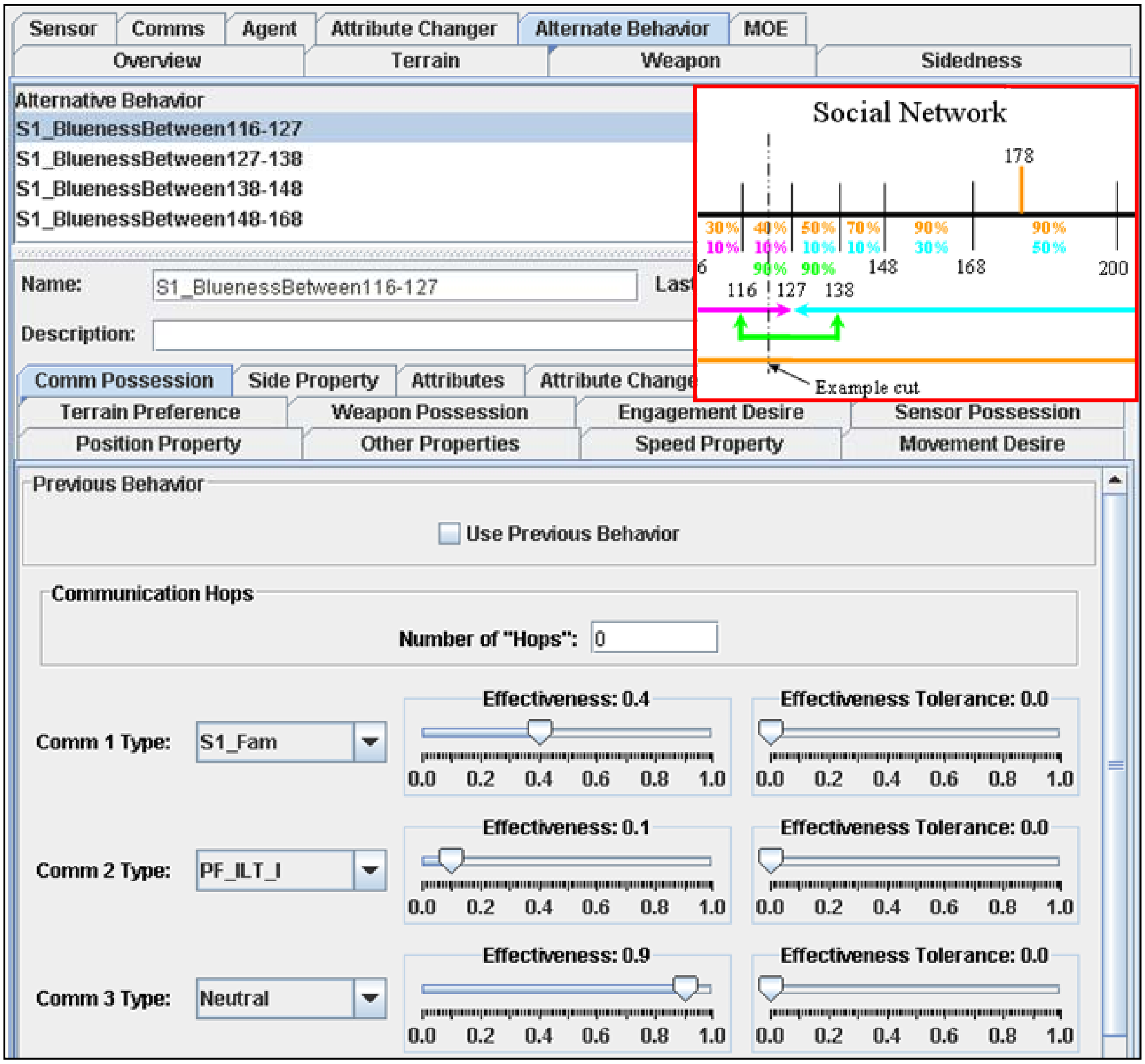


Figure 12. Network participation levels for the example cut line in Figure 13 (from Pythagoras 2.0.0 Version 19). [Best viewed in color]

d. Network Influence Transfer

Attribute changers are conduits for influence exchange. All agents participating in a network hold the same communication device with an attached attribute changer. The attribute changer passes a desired percentage of relative issue differentials throughout the network. An example attachment is shown in Figure 11, where the "SocialNetwork" attribute changer is attached to the PF_ILT_HN communication device. This attribute changer passes a 1% relative issue differential between all networked agents with at least one common issue within their hierarchical issue structures. The construction of this attribute changer is portrayed in Figure 13. Agents that participate in more than one network may receive influence from several sources in a single time step. Pythagoras registers these influences and applies the average to each affected issue within the hierarchical issue structures.

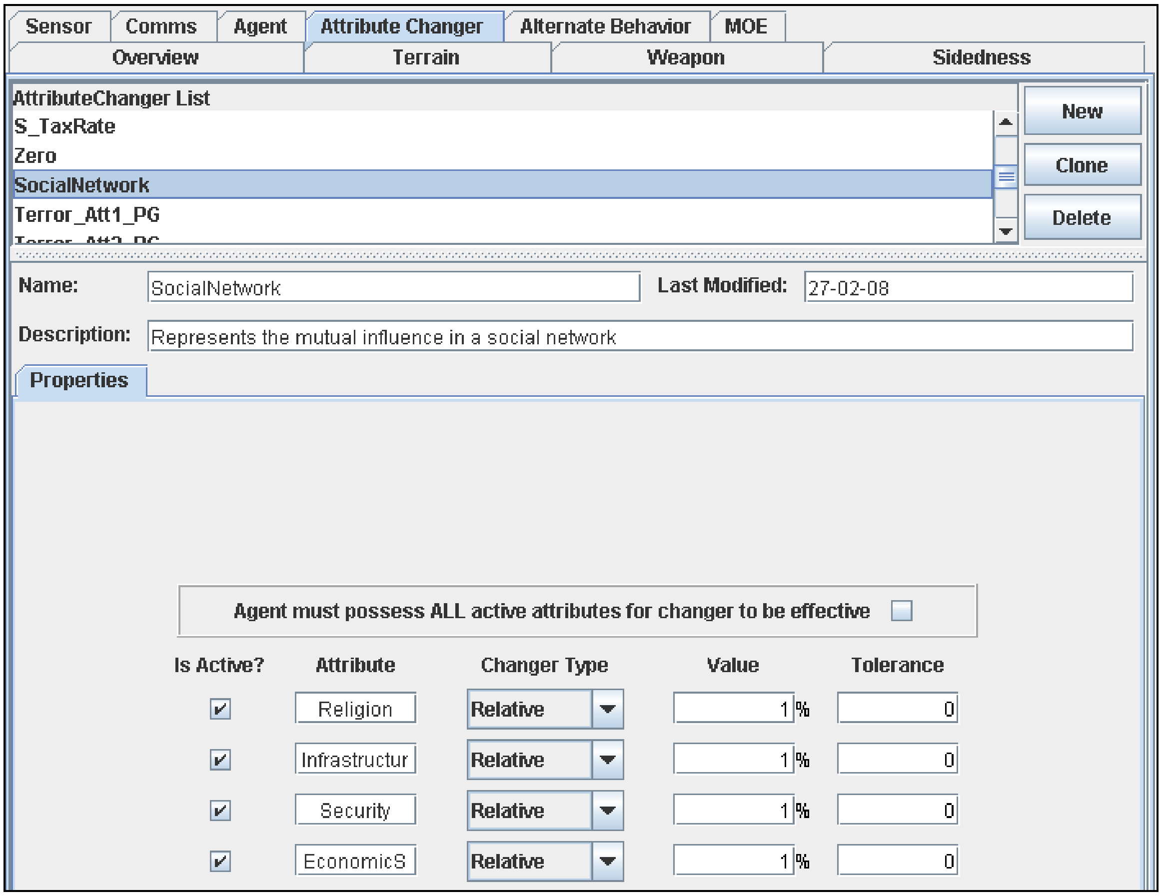


Figure 13. "SocialNetwork" attribute changer implementation (from Pythagoras 2.0.0 Version 19).

e. Trigger Sets

The previous three sections have provided several pictorial representations of agents' resultant settings transitions due to attitudinal shifts from experienced influence on hierarchical issue structures. Thus far, though, we have not provided the methodology that makes these transitions possible. We utilize triggers and alternate behaviors to transfer agents into and out of networks, set the appropriate participation levels, and ensure hierarchical issue structure influence exchanges receive proper weighted color adjustments. Trigger sets are the core components that nearly bring the entire modeling methodology together. We use the term trigger sets because every subpopulation possesses an individual set of triggers and alternate behaviors that are constructed to match their unique hierarchical issue structures; dissimilar hierarchical issue structures require different weighted color splashes for equal magnitudes of influence experienced.

We first attempted to build embedded triggers to capture all possible movements of agents along the blueness color scale. Embedded triggers refer to the process of building every possible combination of attitudinal stances that agents can adopt at any time period during the simulation. If implemented, once the agents depart their initial state, they need never return. Unfortunately, we found that the current Pythagoras setup for constructing triggers induces exponential trigger trees when embedding triggers. Because we must know where each agent is coming from when switching between alternate behaviors, the number of triggers required building every possible combination of attitudinal stances, which are dependent on the changing states of up to ten different attributes, grows exponentially. Thus, we deemed embedded trigger implementations impractical. More information on exponential trigger trees is provided in Appendix F.

Without the use of embedded triggers, we needed to continuously send agents to a known state; the only state we always know for sure is "Initial." We utilize Figures 14-18 to illustrate the trigger set implementation and flow. Figure 14 illustrates the "Initial" hierarchical issue structure state for an S1_PF_ILT_HN agent. The issue values of 698 equate to an initial attitudinal stance of 178 blueness units for S1 agents. This conversion is in accordance with the attribute to color conversion method discussed in III.B.2.d and the specific S1 hierarchical issue structure displayed in Table 3. Remember, even though we have added the capability for agents to react heterogeneously to actions and influences experienced, all agents are initialized homogenously. Next, we implemented the initial triggers in the S1_PF_ILT_HN "Initial" state. These triggers are displayed in Figure 15. There are two extremely important comments concerning settings shown in Figure 15. First, notice that all triggers must be prioritized. Even though we are utilizing only four of ten possible attribute settings within each hierarchical issue structure, we must prioritize ten different triggers. Second, to track attribute changes per attribute, we must input a specific range; in this case, the range is from 600 to 700. These two requirements cause serious problems with respect to accurate attitude representation. These problems are highlighted next.

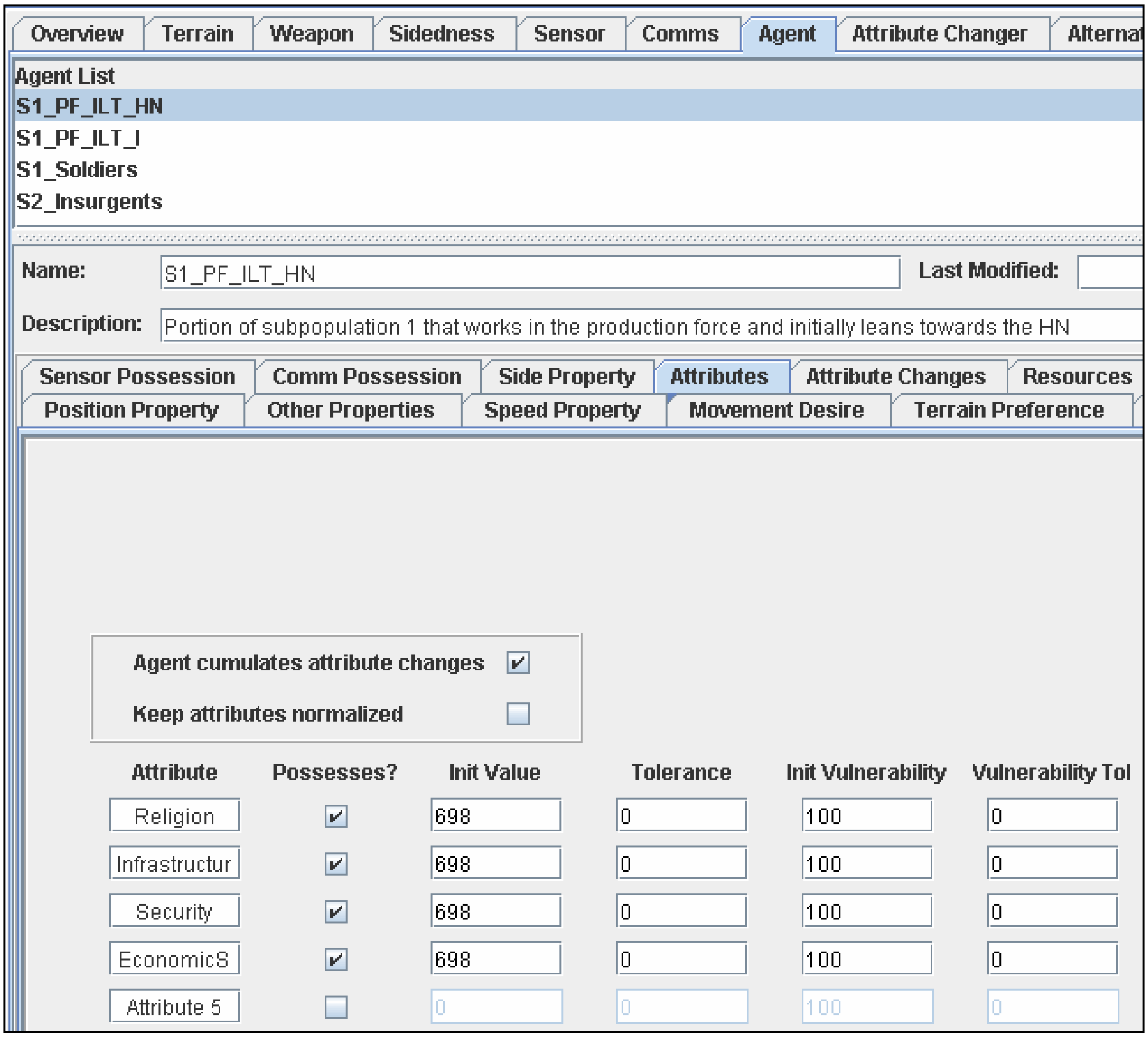
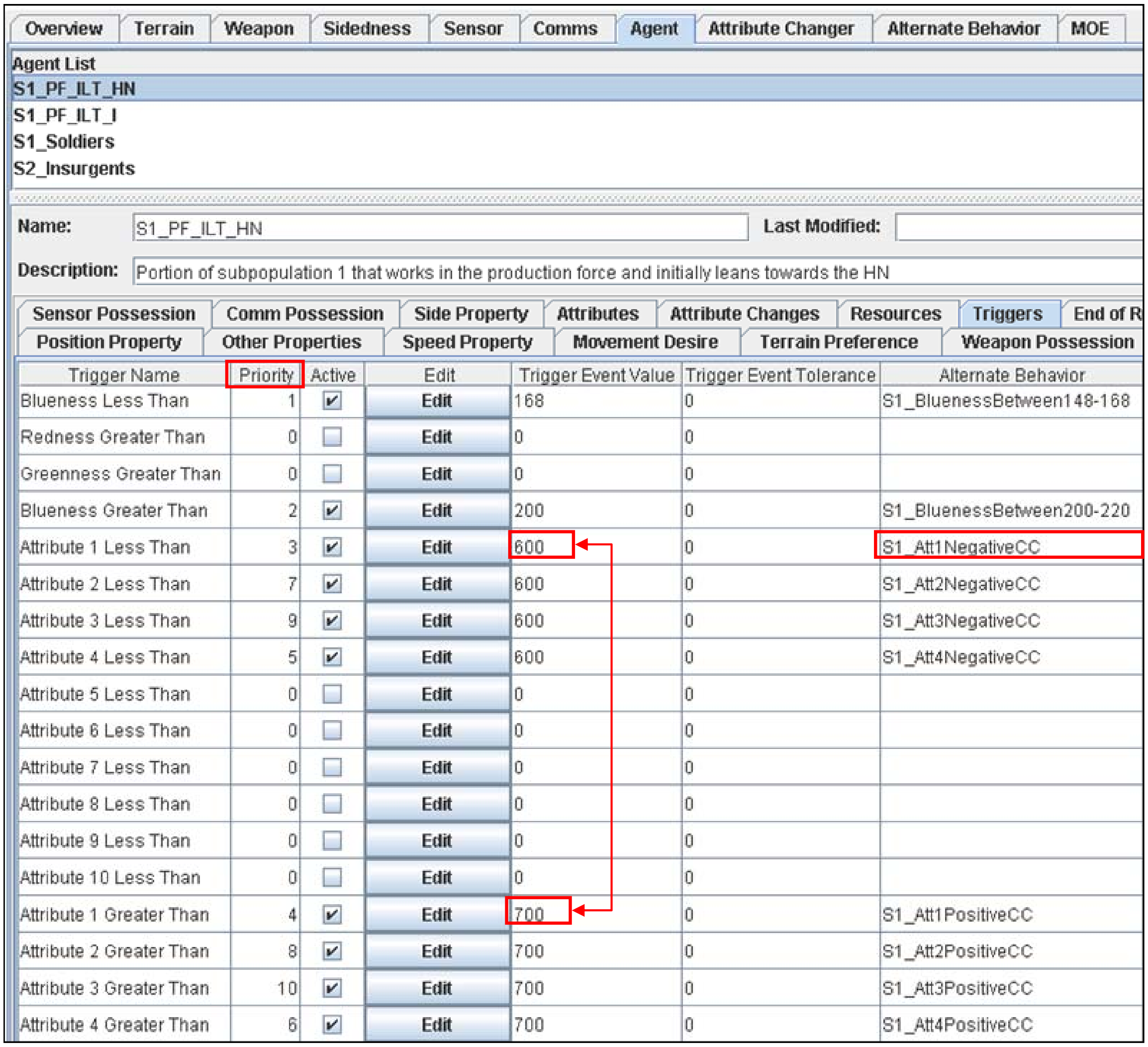


Figure 14. "Initial" hierarchical issue structure state for S1_PF_ILT_HN agent (from Pythagoras 2.0.0 Version 19).



Trigger Name	Priority	Active	Edit	Trigger Event Value	Trigger Event Tolerance	Alternate Behavior
Blueness Less Than	1	☑	Edit	168	0	S1_BluenessBetween148-168
Redness Greater Than	0	☐	Edit	0	0	
Greenness Greater Than	0	☐	Edit	0	0	
Blueness Greater Than	2	☑	Edit	200	0	S1_BluenessBetween200-220
Attribute 1 Less Than	3	☑	Edit	600	0	S1_Att1NegativeCC
Attribute 2 Less Than	7	☑	Edit	600	0	S1_Att2NegativeCC
Attribute 3 Less Than	9	☑	Edit	600	0	S1_Att3NegativeCC
Attribute 4 Less Than	5	☑	Edit	600	0	S1_Att4NegativeCC
Attribute 5 Less Than	0	☐	Edit	0	0	
Attribute 6 Less Than	0	☐	Edit	0	0	
Attribute 7 Less Than	0	☐	Edit	0	0	
Attribute 8 Less Than	0	☐	Edit	0	0	
Attribute 9 Less Than	0	☐	Edit	0	0	
Attribute 10 Less Than	0	☐	Edit	0	0	
Attribute 1 Greater Than	4	☑	Edit	700	0	S1_Att1PositiveCC
Attribute 2 Greater Than	8	☑	Edit	700	0	S1_Att2PositiveCC
Attribute 3 Greater Than	10	☑	Edit	700	0	S1_Att3PositiveCC
Attribute 4 Greater Than	6	☑	Edit	700	0	S1_Att4PositiveCC

Figure 15. S1_PF_ILT_HN "Initial" trigger state (from Pythagoras 2.0.0 Version 19).

As an example, assume the S1_PF_ILT_HN agent in Figure 15 is negatively influenced with respect to religious freedoms, represented by attribute 1. Once attribute 1 is reduced below 600, this agent enters the "S1_Att1NegativeCC" alternate behavior. Figure 16 illustrates the inner workings within this alternate behavior. The first event is the application of the proper weighted color change for the respective decrease in attribute 1. As depicted, six blueness units are subtracted from the agent's attitudinal stance, which represents a negative shift in support for HN. The six units are specific to S1, and match the weighted color splashes for the S1 hierarchical issue structure listed in Table 3. The "All Is Well" color change setting we utilize to implement the color splashes continuously applies one color splash per time step for as long as the agent remains in the alternate behavior. Hence, we needed to ensure the agents remained for exactly one time step; otherwise agents would constantly fall victim to inaccurate attitudinal shifts.

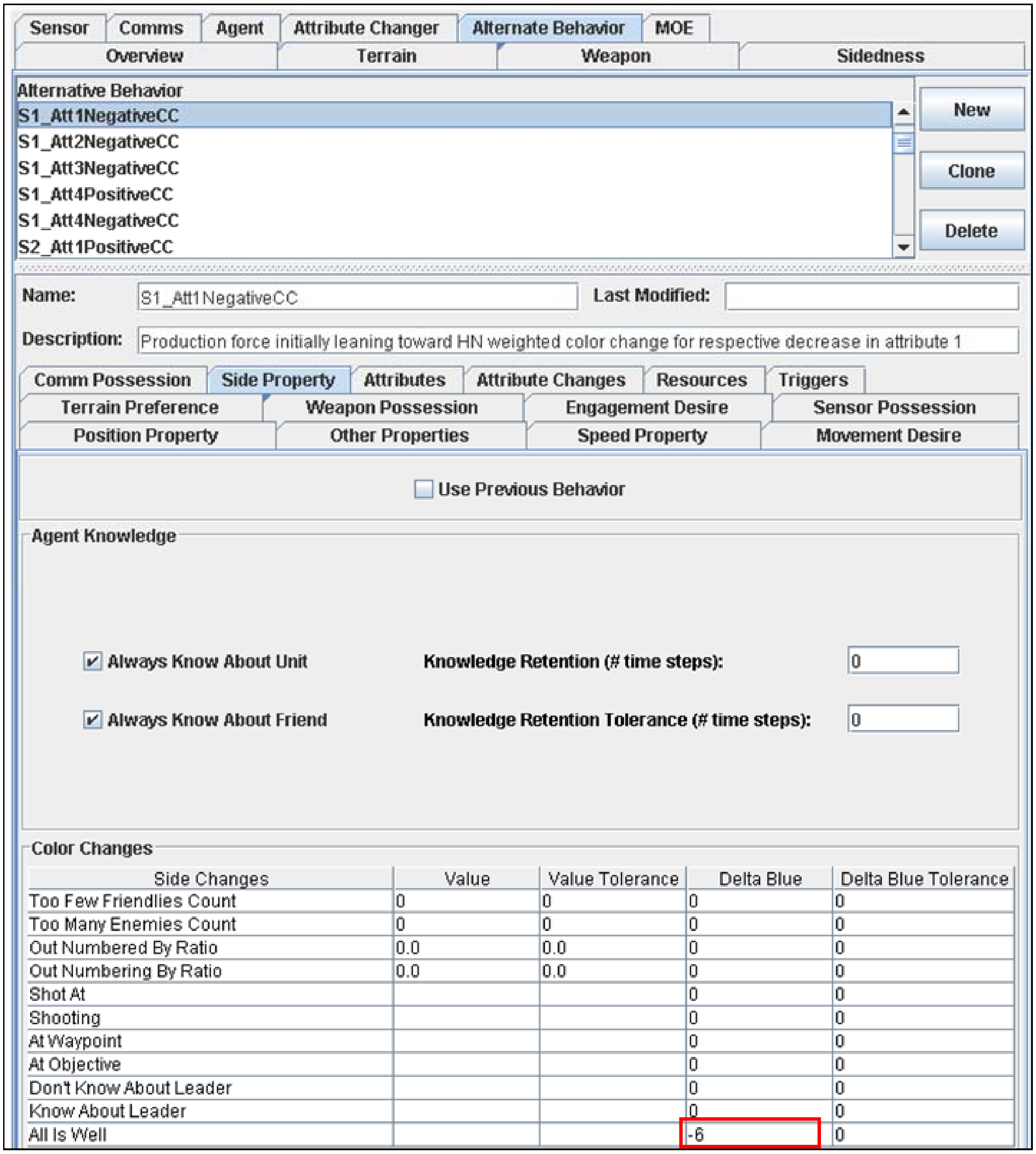


Figure 16. S1 weighted color splash for negative influence on attribute 1 (from Pythagoras 2.0.0 Version 19).

We ensure agents remain in the color change alternate behaviors for a single time step via the setup shown in Figure 17. Each time an agent enters a color change alternate behavior, they are returned to “Initial” after one relative time step. As previously shown in Figure 15, each attribute trigger in the “Initial” state must be bounded. In this example, the attribute triggers are bounded between 600 and 700. Hence, before we send agents back to “Initial,” we must ensure that the tripped attribute, attribute 1 in this case, is reset to a value that will not continually satisfy the “Initial” triggers and dominate the trigger set. We chose to reset tripped attributes to the median values of the initial range each time an agent is triggered back to their “Initial” state, as shown in Figure 18.

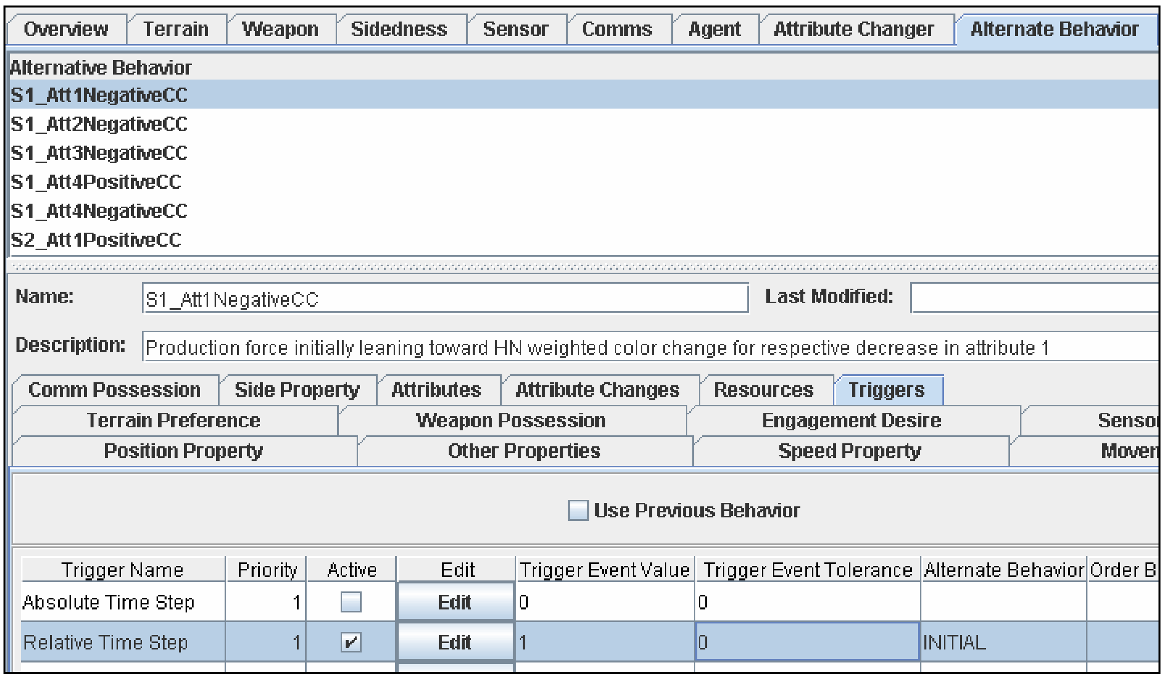


Figure 17. Restricting color splashes to a single time step (from Pythagoras 2.0.0 Version 19).

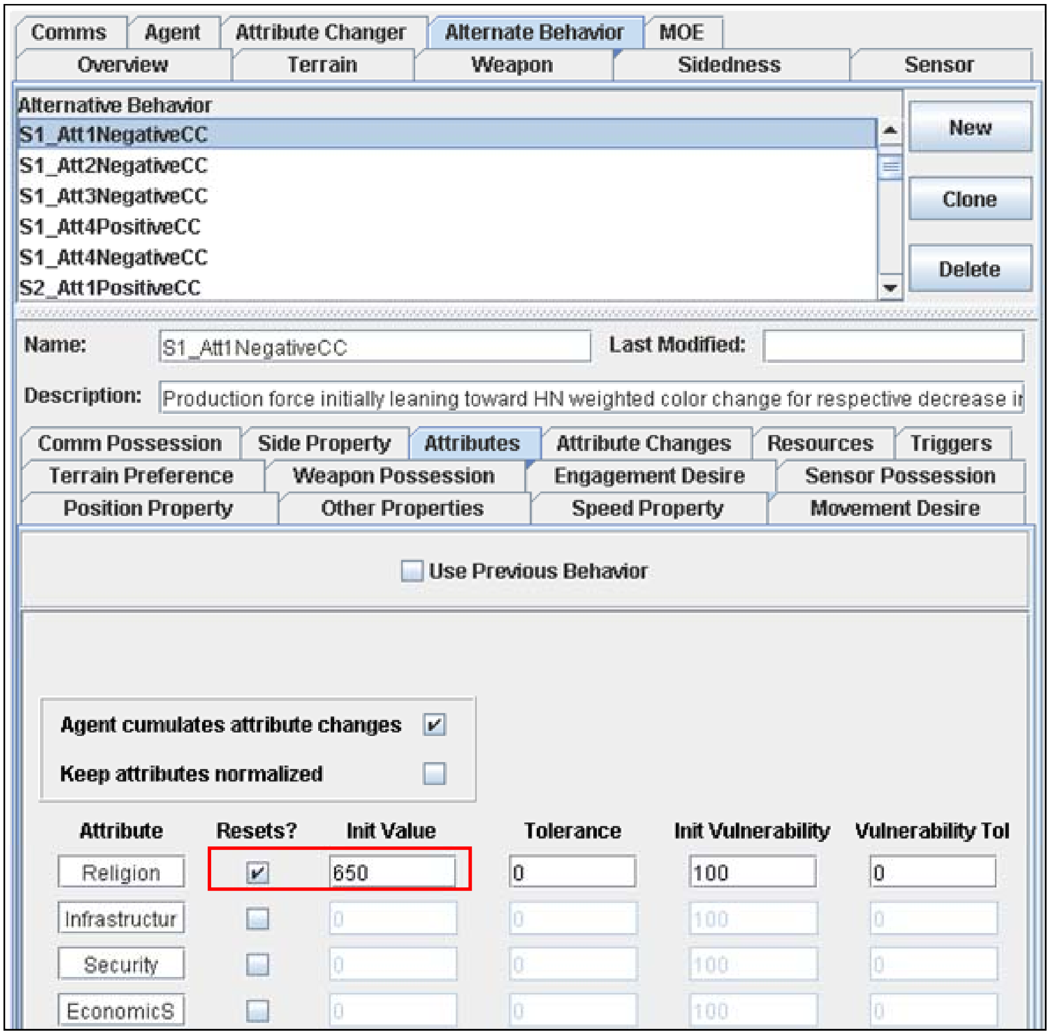


Figure 18. Resetting tripped attributes to prevent infinite triggering upon return to "Initial" (from Pythagoras 2.0.0 Version 19).

This methodology works well to ensure accurate weighted color splashes are implemented throughout the simulation. However, it also corrupts the network influence transfer discussed in III.D.1.d. By resetting the tripped attributes, the true attribute values are not properly tracked. Therefore, percent relative issue differentials passed using the attribute changers, between all networked agents with at least one common issue within their hierarchical issue structures, are not accurate. As well, the requirement for priority entries further degrades attitude representation by inducing two related errors: trigger train and priority lag color losses. Priority lag color loss refers to a phenomenon that enables higher priority triggers to dominate the trigger set and prevent any effective influence performed on lower priority attributes to be properly registered with accurate color splashes. Trigger train color losses result from our continual returns to the “Initial” state, which is necessary since embedded triggers are impractical. In Figure 15, we see that the color triggers are set as the highest priorities. This is the case for all trigger sets. This is to ensure that current attitude representations are always updated prior to registering new attitudinal shifts from experienced influences. However, the further an agent’s attitude shifts from “Initial” during the simulation, the greater the number of color triggers that must be tripped prior to any new influence being registered. Priority lag and trigger trains are correlated and discussed in great detail in Chapter IV, along with the corrupted attitude representations due to attribute resets.

f. Relationship Implementation

We presented the methodologies developed for network transitions, network participation levels, network influence exchange, and the triggers sets that nearly make these methodology mappings possible. As discussed in II.C.2.a, intra-subpopulation and inter-subpopulation influence occur on a daily basis. Each time step within our model represents one day, capturing the idea of daily influences between networked agents. Next, we describe our attempts to capture intra-subpopulation and inter-subpopulation relationships as described in II.C.2.a. Lastly, we also present our attempts concerning implementation of subpopulation leadership characteristics.

g. Intra-subpopulation

Agents within each network exchange influence according to the methodologies presented in III.D.1.c and III.D.1.d. The construction methodology for the S1_Fam and S2_Fam networks inherently captures intra-subpopulation relationships. The effectiveness settings per network are dependent on the attitude differentials between agents and the network majority mean attitudinal stances; this includes the family networks for S1 and S2. Therefore, the further agents depart from their respective family majority mean attitudinal stances, the weaker their relationship with family members and, thus, the lesser the amount of family influence transfer possible. Even though the departed agents hierarchical issue structure possesses the same issues as other members of the subpopulation, the relationship is weak and influence transfer is not very likely.

The magnitudes within the attached attribute changers for the family networks also play a role in intra-subpopulation influence conditions. The higher the percentage input for the respective subpopulation attribute changer, the more the family members influence each other per time step. From Table 5 in III.D.1.b, we list “SocialNetwork” as the attached attribute changers for S1 and S2. The attached attribute changers for S1 and S2 could be completely different in order to capture different intra-subpopulation influence capabilities if desired.

h. Inter-subpopulation

Inter-subpopulation relationships occur because agents are always active in at least two networks. Agents never leave their family network completely, and are also active participants in at least one of the other nonfamily networks. Each of the nonfamily networks is composed of agents independent of subpopulation origin, making inter-subpopulation relationships possible. We would also like to point out a benefit of this two network minimum besides allowing for inter-subpopulation relationships and subsequent influence transfer. If agents from the same subpopulation are influenced to an attitudinal state that is extremely different from their family majority mean attitudinal stance, their relationships with their family are greatly weakened, as desired. However, their abilities to influence each other over the family network are also greatly reduced, which may not be desired because even though they differ from the majority of their family, they may agree with each other concerning HN. This is compensated for via the nonfamily network participation because they are able to properly influence one another over the nonfamily network. Also, these nonfamily links provide agents with at least one common issue within their hierarchical issue structures—the ability to influence each other. Thus, we are able to capture the idea that even though agents do not possess perfectly aligned hierarchical issue structures, their relationship strength allows them to influence one another nonetheless.

i. Leadership

As discussed in III.B.2.c, there is no control in Pythagoras allowing variation of vulnerability settings depending on the relationship between the shooter and target. Hence, it comes as no surprise that although there are leadership settings in Pythagoras, there is no link between these leadership settings and attribute vulnerabilities.

A link between leadership and attribute vulnerability would be a smart manner in which to enable direct representation of respect. We have discussed the current methodology for influence exchange between agents. A beneficial addition would be to increase the amount of influence transfer when networked agents also possess a large leadership setting differential. Higher leadership settings could represent respected individuals within the civilian populace, while lower leadership settings could represent average members of the civilian populace. Therefore, large differentials would result in a pseudo increasing or decreasing of the targeted agent's attribute vulnerability settings, depending on the sign of the differential. The attribute vulnerability settings would not actually be changed, only used as a reference for which the temporary attribute vulnerability setting would be derived. For example, if a respected leader within the community is networked with an average civilian, the leadership differential would be positively large. When the leader influences the average civilian, the temporary attribute vulnerability value used to determine the actual amount of influence transfer would be higher than the listed baseline attribute vulnerability setting. The amount of increase would be a percentage increase based on the leadership differential.

In the absence of this capability, we captured some leadership representation without using the leadership settings. We built individual agents acting as subpopulation leaders. These leader agents, S1Leader and S2Leader, possess communication devices with more powerful attribute changers than the rest of the civilian populace. These attribute changers provide them the capability to introduce more influence into their respective family networks; a workaround method for representing respect. The influence injected by S1Leader and S2Leader is one way with no feedback gathered from their respective members. Leader communication devices are "Talk" only, while the respective family network communication devices, S1_Fam and S2_Fam, are set to "Listen" only with respect to the leadership channels used.

The methodology implementation for capturing leadership is provided in Figures 19-20. Figure 19 shows that S1 members experience influence exchange over channel 3, but receive influence only, over channel 7. Figure 20 illustrates the S1Leader network. The S1 leader injects influence on S1 members over channel 7 via the "SocialNetwork_Leader" attribute changer. This attribute changer passes 4% relative issue differentials, vice the 1% used for the "SocialNetwork" attribute changer. One thing to keep in mind when utilizing this methodology is that agents designated as leaders will remain leaders regardless of their attitudinal stances. In other words, even though an agent begins as a leader within the soldiering ranks, if influenced to a point of adopting the insurgency, then this agent will be a leader within the insurgency.

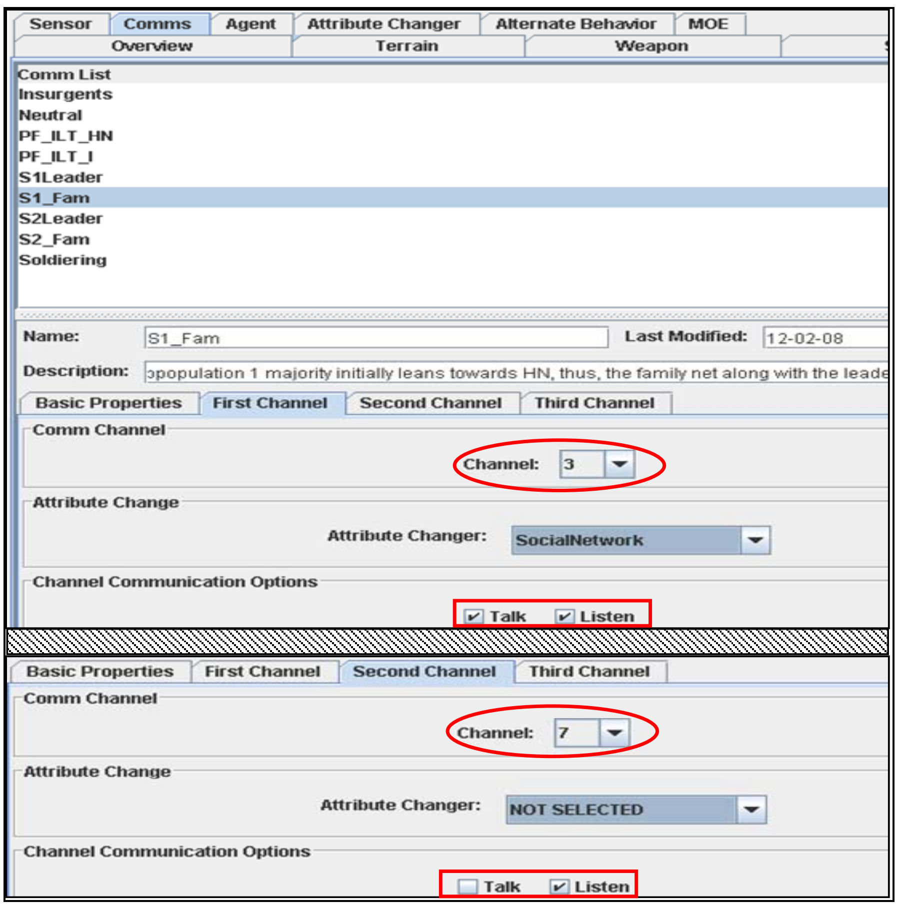


Figure 19. S1 family network construction for receiving leadership influence (from Pythagoras 2.0.0 Version 19).

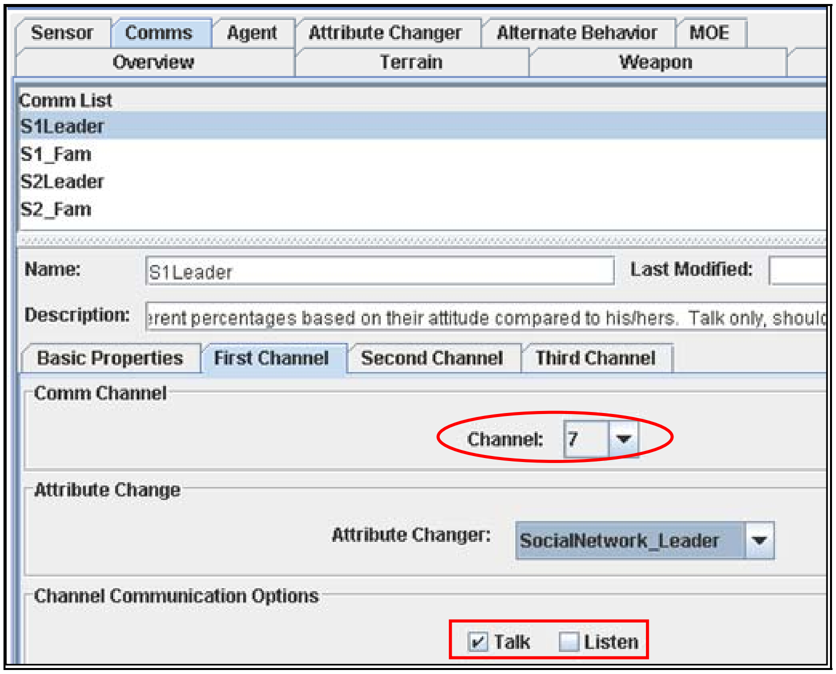


Figure 20. S1 leadership network for injecting influence to all S1 members (from Pythagoras 2.0.0 Version 19).

2. Limitations

One limitation to discuss is the application of proper weighted color splashes on agents. As discussed in III.D.1.e, we utilize the "All Is Well" color change functionality within the "Side Property" tab of the "Alternate Behavior" page to implement appropriately weighted color splashes. This methodology comes with two associated limitations. First, as shown in Figure 17, because we must choose a specific alternate behavior to send each agent to after the splashes, even if exponential trigger trees were deemed practical by another user, this methodology makes them impossible. Second, when using the "All Is Well" color change functionality shown in Figure 16, it only performs its function if all other side changes above it are not satisfied. Hence, as we discuss in III.E.1.d, this restricts our capability to implement a characteristic of the economic model of insurrection. Therefore, the fact that there is no simple method for an agent to self-color is a limitation within Pythagoras.

The next problem area encountered stemmed from attempting to build embedded trigger sets. Embedded trigger implementations resulting in exponential trigger trees is not the primary concern. The important insight to be gleaned is uncovered by asking why we attempted to build embedded trigger sets in the first place. We were attempting to link attribute change to color change. The fact that there is no direct link between attributes and color is a major limitation within Pythagoras that caused several problems and required workarounds for our modeling methodology research efforts. We believe the utilization of trigger sets is the only method in Pythagoras capable of making this link; however, several attitudinal representation errors result from the trigger set methodology. These errors emerge in the forms of priority lag color loss, trigger train color loss, and inaccurate social network influence transfer.

3. Recommendations

Our recommendations for addressing the limitations encountered during the social network methodology research are more easily understood following the presentation of Chapter IV. Chapter IV provides great detail on priority lag color loss, trigger train color loss, and the inaccurate social network influence exchange errors resulting from the current requirements within Pythagoras for implementing the trigger set methodology. Hence, the recommendations we offer concerning the social network limitations are provided in IV.D.

E. ECONOMIC INSURRECTION MODEL MAPPINGS INTO THE PYTHAGORAS MODELING ENVIRONMENT

In accordance with the economic insurrection model synopsis in II.C.3.a, the resultant mappings to capture its essence are provided. We constructed three abstract feature properties within Pythagoras to spatially represent the three economic sectors of the economy: insurgent sector, production force sector, and soldiering sector. Within each economic sector, agents receive wages, pay taxes, and move to the appropriate economic sector that correlates to their respective attitudinal stances. We discuss the methodologies for these implementations first. Then we discuss limitations contributing to our inability to capture HN action adjustments based on feedback and agent risk level adjustments based on their perceived probability of the insurrection being successful.

Once again, take note of the blue highlights and red highlighted cutouts within each figure provided, as they aid in understanding of the presented modeling methodologies.

1. Mappings

a. Wages

All subpopulations that value economic security contain an economic security issue within their hierarchical issue structures. Payments for agents participating in each of the three economic sectors are implemented via economic security agents armed with indirect fire weapons possessing attached attribute changers that target the economic security attribute. Figures 21-22 illustrate payment implementation for agents actively participating in the production force. The Production Force Economic Security Center/Left/Right (PF_ES_Center/Left/Right) agents in Figure 21 possess a Production Force Economic Security (PF_ES) weapon used to represent paychecks being distributed to the production force. Figure 22 shows the fire rate for the PF_ES weapon as well as the attached PF_ES attribute changer settings. As shown, the production force workers are paid 15-25 economic security units every 30 days. We utilize three PF_ES agents in efforts to maximize successful payments to production force members by ensuring payments are provided over the majority of the production force economic sector. This reasoning will become more apparent in III.F. The insurgent and soldiering economic sectors also utilize three agents to distribute payments to their respective active participants. The agents are named I_ES_Center/Left/Right and S_ES_Center/Left/Right. The implementation methodology remains the same for each set of economic security providers.

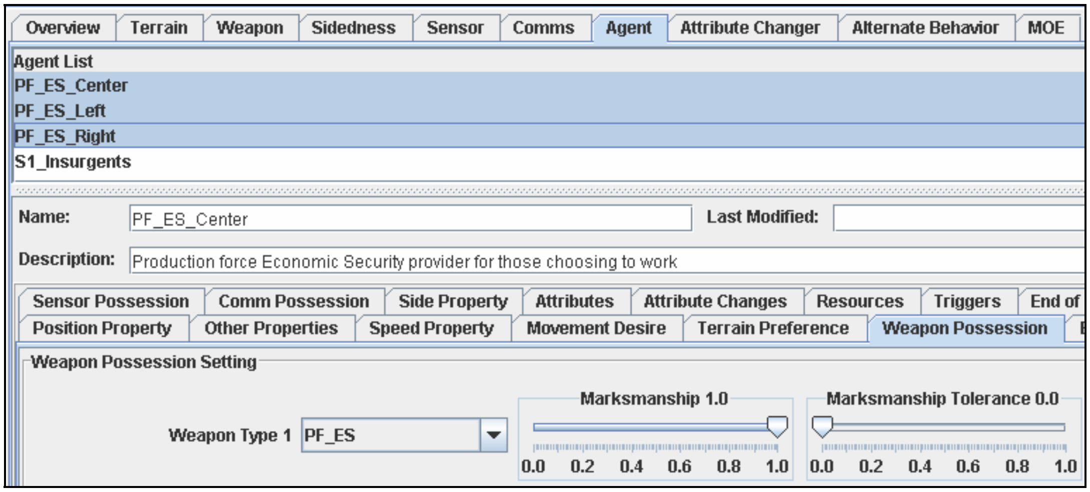


Figure 21. Economic security agents weapon for providing wages to active participants in the production force (from Pythagoras 2.0.0 Version 19).

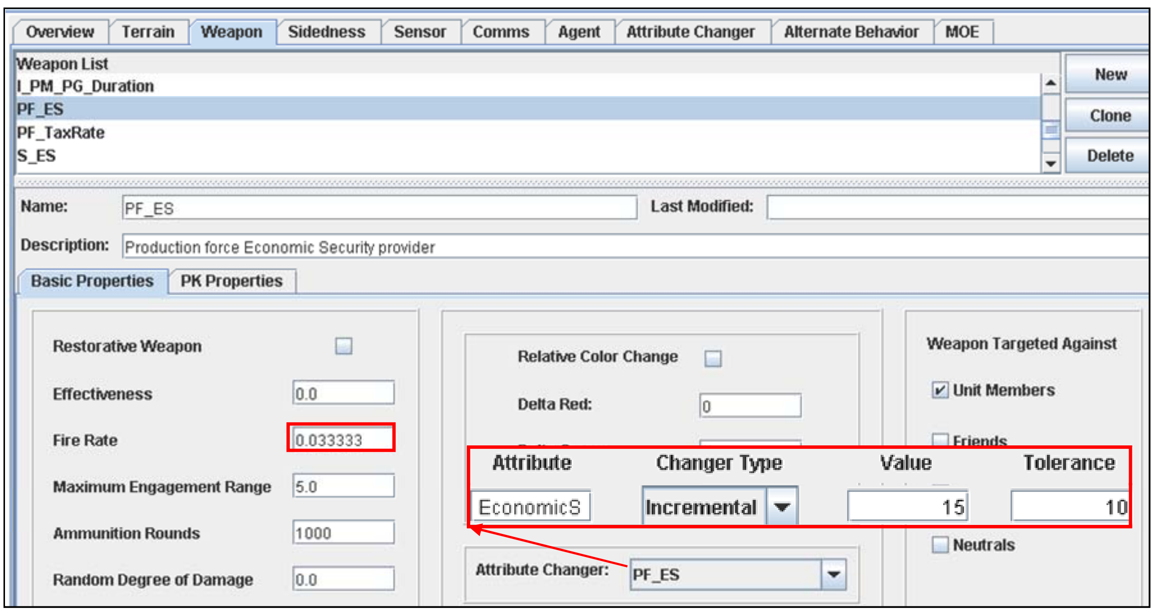


Figure 22. Production force payment rate and magnitude (from Pythagoras 2.0.0 Version 19).

b. Taxes

The production force and soldiering economic sectors suffer taxes, while the insurgency sector does not. To capture taxes, we attached attribute changers to production force and soldiering economic sectors, as shown in Figure 23. Control over attribute changers attached to terrain pieces is somewhat limited. As seen in Figure 23, time periods for length of activation must be entered. Hence, for our scenario, with each time step representing one day, the taxes for the production force workers and soldiering forces are taken out daily for one year. The attribute changer is not attached to a weapon and, therefore, does not have an associated fire rate. Hence, the attribute changer takes designed action every time step from start time to end time. There is currently no functionality in Pythagoras allowing fire rate manipulation for these particular attribute changers.

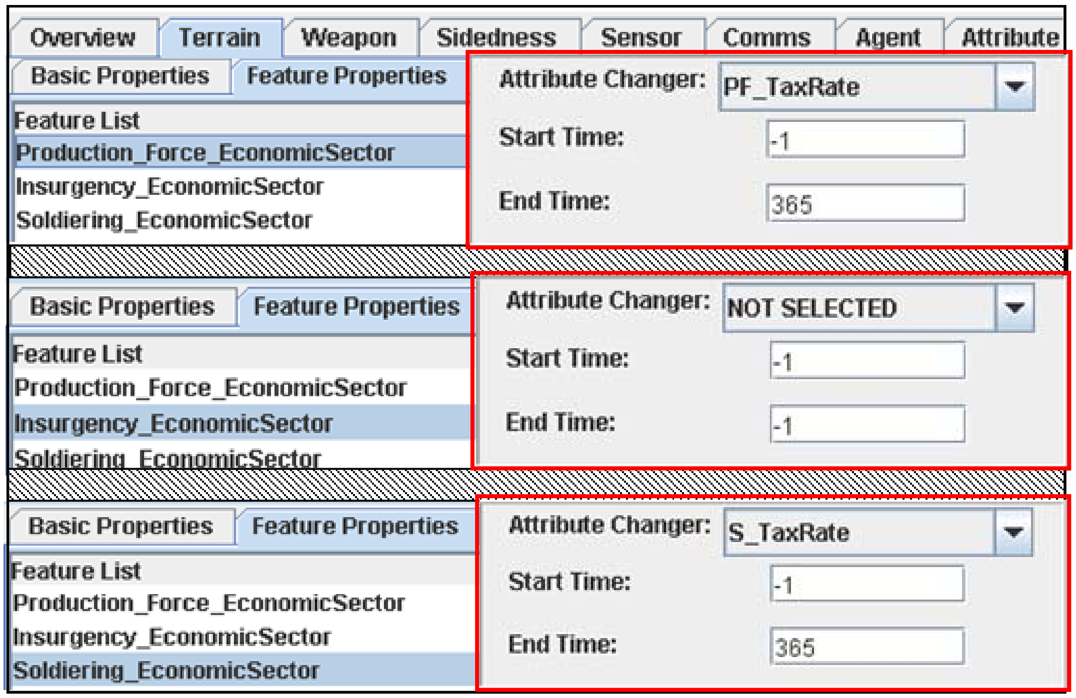


Figure 23. Tax rate implementation for the three sectors of the economy (from Pythagoras 2.0.0 Version 19).

c. Movement

The capability to instantiate agent movement towards designated pieces of terrain is extremely limited in Pythagoras. There are settings per agent that allow inputs for "Prefer Good Terrain If" and "Avoid Bad Terrain If," but agents only evaluate terrain within one pixel of their position for these conditions. These settings are more useful in preventing agents from getting stuck in place within a heavily urban type scenario. For our economic movement desires, these settings were not helpful.

Implementing agent movement between the three economic sectors proved to be an extremely difficult task. In order to allow agents to move to the economic sector that correlated to their attitudinal stances, we needed to construct 34 movement agents with specific leadership settings within the "Other Properties" tab, as well as 18 extra sidedness configurations. Next, we needed to ensure that the "Toward The Leader If Farther Than" movement desire was instantiated for all possible alternate behaviors for each subpopulation. The distance input for this movement desire was based on the sizes of the three economic sector feature properties. Each economic sector is 1,200 x 400 pixels in size for our scenario. Thus, we placed the movement agents in the centers of the economic sectors and set the movement desires to: "Toward The Leader If Farther Than" 150 pixels. This methodology ensures every agent within the scenario, regardless of attitudinal stance, will always see one movement agent as their leader. Thus, they will move to within 150 pixels of this movement agent, and ultimately be within the proper economic sector, receiving proper wages, and paying the appropriate taxes.

d. Probability of Successful Insurrection

We did not capture this aspect of the economic insurrection model. Thus, HN does not obtain feedback concerning their effectiveness and adjust accordingly, nor does the civilian populace sense the strength of the insurgency and adjust risk levels.

Due to the manner in which we splash agents with weighted color changes, as discussed in III.D.1.e and Figure 16, we are unable to utilize the "Out Numbered By Ratio" or "Out Numbering By Ratio" side changes. These side change settings are designed to adjust affiliation based on the ratio of friends to enemy and vice versa. As well, they possess tolerance settings that would allow the idea of perception to also be implemented. Hence, these settings could be utilized to make adjustments to agent risk levels depending on their perceived probability of a successful insurrection. However, we were unable to utilize this added functionality. Essentially, we had to choose which characteristic was more important and, as we have discussed, the attribute change to color conversion is the backbone of our modeling methodology.

Hence, it trumps all other desired characteristics, including the perceived probability of a successful insurrection for the civilian populace to use for adjusted risk levels.

Concerning HN actor agents and PF_ES and S_ES agents, there are no trigger options that allow these agents to adjust actions based on feedback. Feedback refers to the capability to utilize information on the number of civilians participating in the insurgency and adjusting global actions, production force and soldiering wages, taxes, etc. These actor agents can utilize the “Out Numbering By Ratio” and “Out Numbered By Ratio” side change functions, but there is no option to enter an alternate behavior based on the results, which is necessary in order to enter the desired action adjustments. Hence, even though we could utilize the side change functions for actor agents, they are not useful for our feedback implementation desires.

2. Limitations

The first limitation encountered with respect to our economic insurrection model modeling efforts consisted of limited control over attribute changers attached to terrain. These specific attribute changers must take action on every time step, regardless of time step definition.

On a larger scale, the next limitation encountered involved lack of movement capability with respect to terrain. It is extremely difficult to steer agents to terrain pieces that are designed to match their attitudinal stances. The methodology we devised requires extra agents, alternate behaviors, movement desires, and leadership settings, even though our scenario contained only three terrain pieces. As well, this methodology results in a bit of economic sector shift scripting.

The next limitation stems from the inability of agents to self-color. This deficiency forces us to utilize the “All Is Well” side change property, which in turn, eliminates our ability to represent varying risk levels based on perception of a successful insurrection with the “Out Numbered By Ratio” and “Out Numbering By Ratio” side change properties.

Lastly, no options exist in either the side change property tab or the agent triggers tab that allow entry into an alternate behavior due to ratios of friends versus enemies. This prevents the implementation of feedback, which would allow actor agents to adjust actions based on the collective attitudinal stance of the civilian populace.

3. Recommendations

The terrain attribute changer limitation is easily circumvented by making mathematical adjustments to the attribute changer magnitudes in order to properly represent the desired tax rate. However, with the input values restricted to integer only, the smaller the time period represented per time step, the greater the chance that accurate tax rate representation cannot be achieved. Hence, the ability to manipulate the terrain attribute changer fire rate would prove beneficial for a wider range of time step options.

Agent movement options towards pieces of terrain would be extremely beneficial for our modeling efforts and greatly reduce unnecessary complexity and scripting. One recommendation is the addition of the ability to assign identification numbers to user-built terrain pieces. Then, within the movement desires tab, also add an option for "Move into terrain piece: <u>input identification number</u>." This would create the ability to move agents to pieces of terrain based on their attitudinal stances. Once the agents move to their proper terrain piece, then they can be contained within it using the already established functionality of the "Prefer Good Terrain If" and "Avoid Bad Terrain If" settings.

It is imperative to develop a method for agents to self-color. With this capability addition, two limitations are removed. First, the option to utilize embedded trigger trees is revived if a user deems them practical for their modeling efforts. Second, the requirement to use the "All Is Well" side change property is lifted, allowing the use of the "Out Numbered By Ratio" and "Out Numbering By Ratio" side change properties. This would provide added capability to adjust agent risk levels based on perceived probability of success of an insurrection.

The ability to trigger agents into alternate behaviors from the side change property listings would enable implementation of feedback for actor agents. However, this may cause complications by allowing agents to enter alternate behaviors from too many places within Pythagoras. Moving the side property change listings into the trigger page would consolidate possible alternate behavior entry options and increase the capability currently offered by the side property change listings. This consolidation would increase Pythagoras HBR capabilities, while simultaneously simplifying user requirements.

Lastly, we would like to briefly comment on the “Resources” functionality within Pythagoras. We first attempted to implement the economic insurrection model solely with resources vice treating economic security as an issue within the hierarchical issue structures. The potential to capture more economic characteristics exits within the resource functionalities: average agent savings, wage rates, average spending rates, risk levels, and actor budget representations. Figure 24 illustrates these potential resource functionalities within Pythagoras. However, sidedness complications, inflexibility with resource movement desires, and the necessity to separately link resource changes to color change as well, caused this methodology to be abandoned.

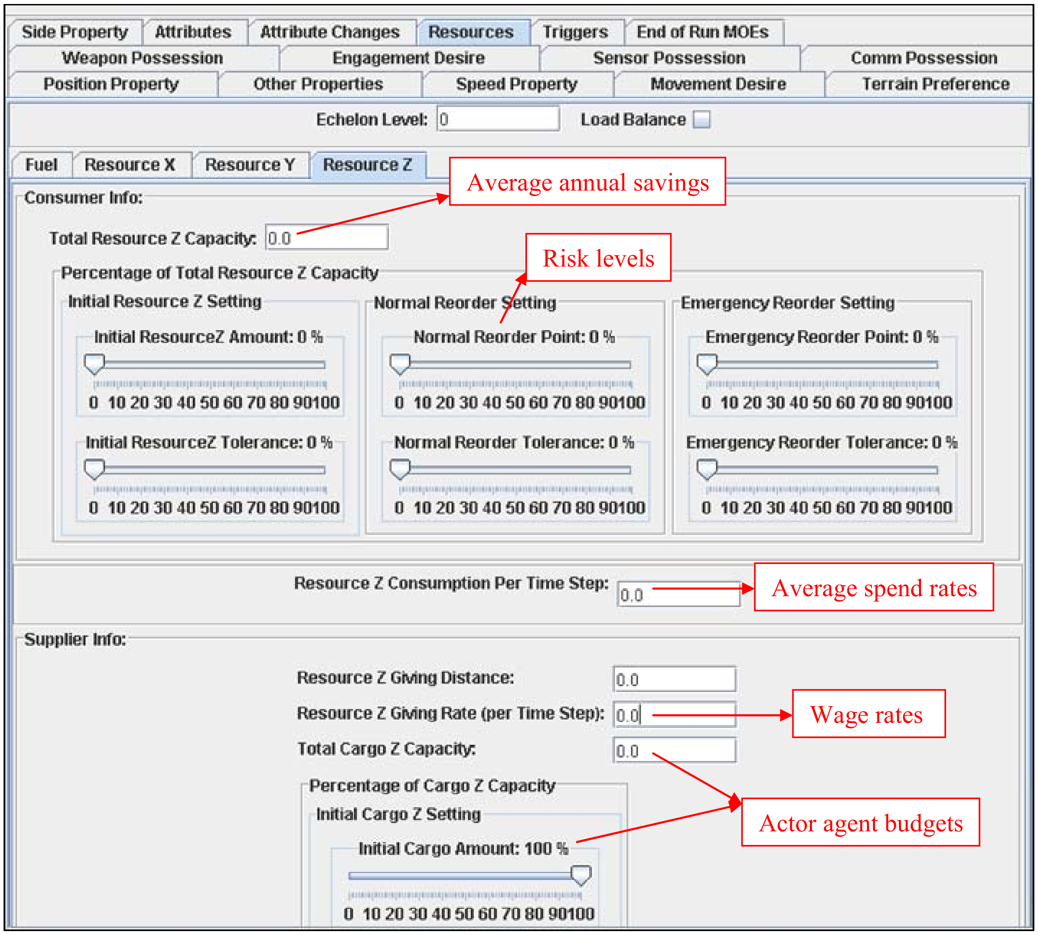


Figure 24. Potential economic characteristic representations using "Resource" functionality (from Pythagoras 2.0.0 Version 19).

Agents can resupply others and be resupplied only if the other agent possesses a sidedness resulting in other than enemy affiliation. Granted, in combat one may not normally supply or get resupplied by an enemy; however, in an IW environment, this option is quite feasible. As an example, if someone is forced to live without economic security for a period of time, or their economic security is depleted below their individual risk level, then they may choose to work for anyone who is willing to pay them, including their enemies. In order to make resources more applicable for HBR representation within the IW realm, we recommend the following changes: remove the other than enemy restriction concerning resource supply, add movement desires allowing movement toward enemies needing and giving resources, and consolidate the movement desires concerning resources into a single resource movement desire option containing a dropdown list. This list should allow entry of affiliation in order of desire with respect to seeking resupply. For example, when economic security falls below designated risk levels, the agent seeks economic resupply first from friends, then from neutrals, and eventually, from anyone.

F. SUMMARY

We have presented our modeling methodology for implementation of the RUCG analytic social theory model suite, the assumptions accompanying these methodologies, limitations observed, suspected attitude representation errors induced from these limitations and, when able, recommendations for capability modifications to minimize or eliminate the problem areas encountered. Figure 25 is a snapshot of this methodology implemented in Pythagoras 2.0.0 Version 19. Every mapping discussed in Chapter III is displayed by Figure 25. We can see that the implementation of three relatively simple analytic models for merely two subpopulations using seven networks becomes somewhat complex quite easily.

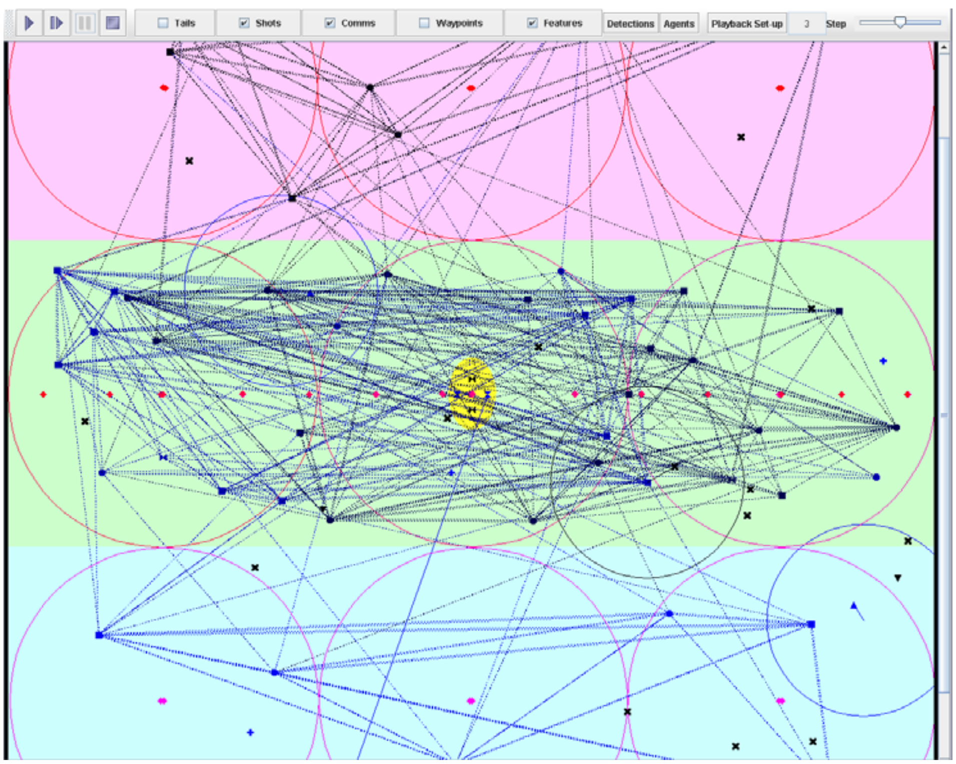


Figure 25. Snapshot of RUCG analytic social theory model suite implementation in Pythagoras 2.0.0 Version 19 (from Pythagoras 2.0.0 Version 19) [Best viewed in color].

Figure 26 is a simplified flow diagram for capturing the modeling methodology flow described in Chapter III. We discussed three major problems with respect to attitude representation concerning the methodology presented: priority lag color loss, trigger train color loss, and inaccurate influence exchange throughout the social network. The methodology areas where these problems arise are annotated on Figure 26 by the red and yellow splashes. Priority lag and trigger train color loss are somewhat manageable, but the improper influence exchange across the social network is unmanageable and causing catastrophic attitude representation errors. We investigated these suspected error sources in detail in order to gain complete understanding concerning their causes and magnitudes. The results of this analysis are provided in Chapter IV.

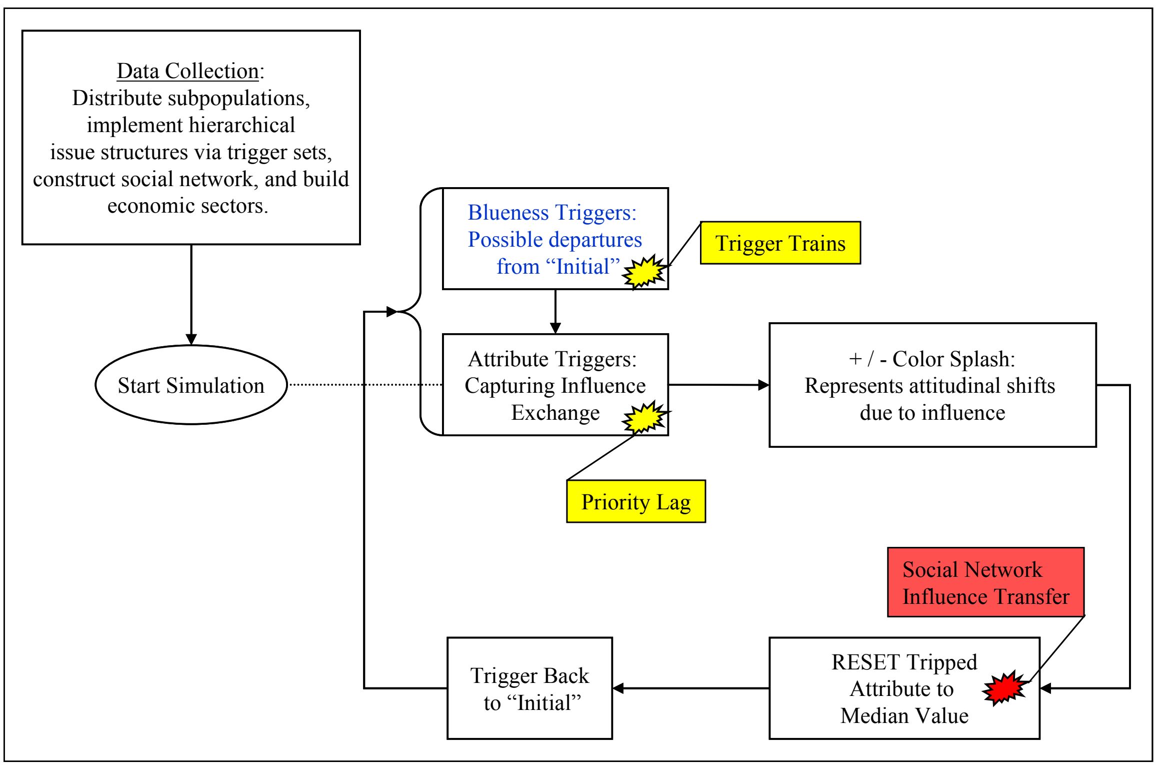


Figure 26. Simplified flow diagram for RUCG analytic social theory model suite modeling methodology within Pythagoras 2.0.0 Version 19. [Best viewed in color]

IV. ATTITUDE REPRESENTATION ERROR ANALYSIS

An error the breadth of a single hair can lead one a thousand miles astray.

–Anonymous

A. INTRODUCTION

We presented our modeling methodologies in Chapter III with an emphasis placed on suspected attitude representation errors due to priority lag color loss, trigger train color loss, and inaccurate social network influence exchange. These three error sources are functions of limitations in Pythagoras 2.0.0, requiring the trigger set methodology discussed in III.D.1.e to link attributes to colors. This chapter provides more detail on these error sources and recommendations for minimizing and/or eliminating them. First, we present a simplified model constructed to capture the priority lag and color loss error inductions in action, the experimental design utilized for verifying and quantifying these errors, and the results and insights gleaned. Then, we leverage the results presented by CDR Seitz concerning the inaccurate social network influence exchange, and provide recommendations for capability additions to Pythagoras for addressing the various error inductions due to current methodology requirements.[27]

B. THE EXPERIMENT

Throughout our methodology research, we strived to continuously test each mapping idea incrementally as we constructed our model. This policy ensured we kept track of successes and failures in mapping the respective RUCG analytic model concepts into Pythagoras 2.0.0 and prevented us from becoming lost in our own modeling efforts. We found that each model, individually, appeared to work as expected. In essence, for each individual methodology, when we removed all stochastic settings, we could manipulate settings and observe expected response trends. However, when we combined

[27] CDR Thorsten Seitz, German Navy, "Representing Urban Cultural Geographies in Stability Operations, Analysis of a Social Network Representation in Pythagoras," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2008.

all three model mappings and began to increase the number of agents, we started seeing unpredictable responses, even though the model was still setup deterministically. Specifically, even when only positive influence was being injected into the civilian populace, negative attitudinal shifts were still occurring. Therefore, we decided to construct simplified models that maintained all of the modeling methodologies described in Chapter III, and develop experimental designs to explore for the causes of these unpredictable responses in conjunction with the effects of the suspected attitude representation error sources. The following model and experimental design focus on the priority lag and trigger train color loss aspects of attitude representation error.

1. Simplified Model

The unpredictable responses were first discovered at the state of methodology construction shown in Figure 25. However, we were able to greatly reduce the model in size and maintain the same level of complexity with respect to our modeling methodology. Figure 27 illustrates the simplified model utilized.

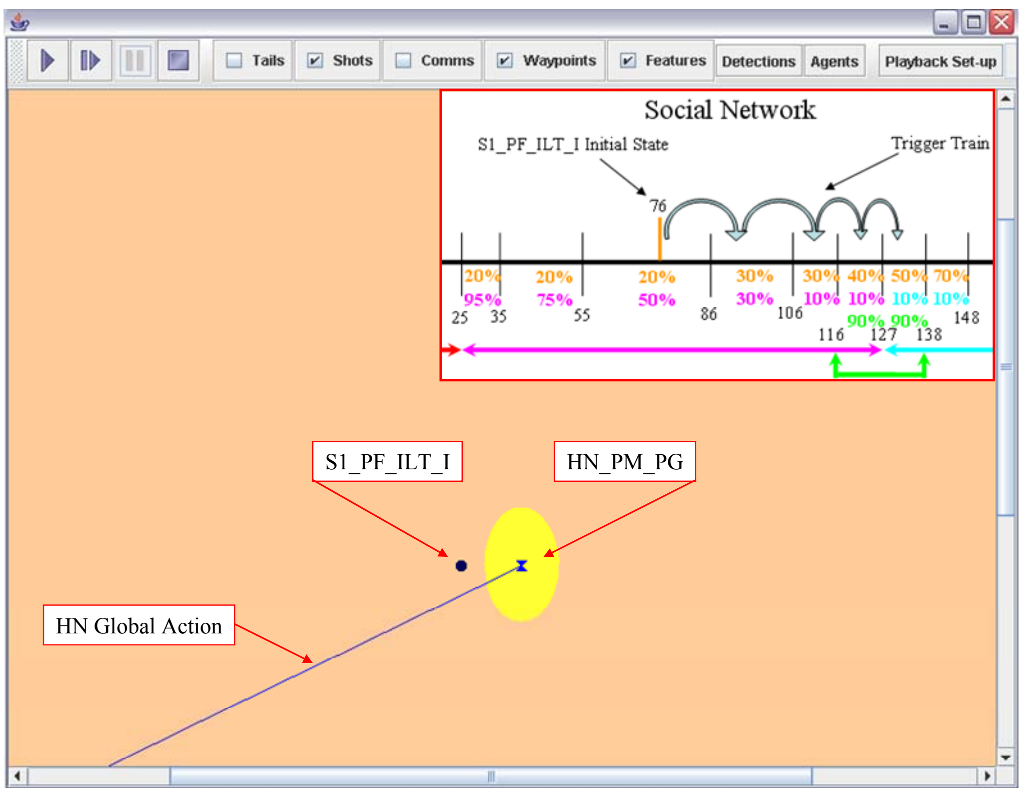


Figure 27. Snapshot of simplified model created for priority lag and trigger train color loss analysis (from Pythagoras 2.0.0 Version 19). [Best viewed in color]

We needed only one S1_PF_ILT_I agent and one HN_PM_PG to gain an understanding of why the priority lag and trigger train color losses occur, as well as the magnitude of their effects. The model shown in Figure 27 portrays a HN_PM_PG actor agent executing unopposed influence actions against an S1_PF_ILT_I agent. These actions are executed every time step against all four issues within the S1_PF_ILT_I hierarchical issue structure, and all are perceived as good. This unopposed simultaneous influence was by design, in an effort to flush out the suspected problems caused by priority lag and trigger trains as discussed in III.D.1.e. First, we wanted to capture attitudinal response to simultaneous influence against all issues within a hierarchical issue structure, to help understand the effect of the forced priority scheme. Second, we wanted to see the model response to an agent experiencing relatively quick attitudinal shifts. Lastly, all tolerance settings were set to 0.0 to force deterministic attitude responses to these positive influences. This allowed us to perform a comparison of the simulation attitudinal stance output to a spreadsheet model containing the true attitudinal stances when priority lag and trigger train color losses were removed.

2. Experimental Design

This experiment was needed to develop an understanding of agent attitudinal responses to effective influences experienced. Hence, the factors of interest are the magnitudes of effective influences injected on the civilian populace (HN_PM_PG attribute changer settings). The response of interest is attitude representation (S1_PF_ILT_I agent blueness values). We utilized 20 levels for each factor. The levels used are all quantitative and range from 1 to 20. These factor levels ranges represent 0.1%-2% attitudinal shifts per issue per time step. These percentages are derived by dividing the factor level values by 1,000, where 1,000 is the maximum attribute value possible within Pythagoras.

We chose to use an NOLH design for our experiment. This design provides us efficiency and space-filling characteristics for our quantitative factors, and is quite suitable for our simplistic simulation experiment.[28] With 4 factors and 20 levels, we capture a sufficient portion of the design space with only 17 design points. The design matrix used for this experiment is displayed in Table 6.

Design Points	Factors			
	Attribute 1	Attribute 2	Attribute 3	Attribute 4
1	7	20	16	8
2	2	6	18	12
3	3	9	2	6
4	5	13	7	20
5	15	19	9	3
6	20	7	8	16
7	13	5	20	7
8	12	18	15	19
9	11	11	11	11
10	14	1	5	13
11	19	15	3	9
12	18	12	19	15
13	16	8	14	1
14	6	2	12	18
15	1	14	13	5
16	8	16	1	14
17	9	3	6	2

Table 6. NOLH Design Matrix (4 Factors, 20 Levels, 17 Design Points).

The space-filling properties for this NOLH design are captured with the scatter plot matrix displayed in Figure 28. Design matrices are classified as nearly orthogonal when all intercolumn correlations reside in the following interval: (–0.03, 0.03).[29] As we can see in Table 7, these requirements are met with our design matrix.

[28] For more information on NOLHs see: Thomas M. Cioppa and Thomas W. Lucas, "Efficient Nearly Orthogonal and Space-Filling Latin Hypercubes," *TECHNOMETRICS*, February 2007, Vol. 49, No. 1, pp. 45-55.

[29] Ibid., p. 45.

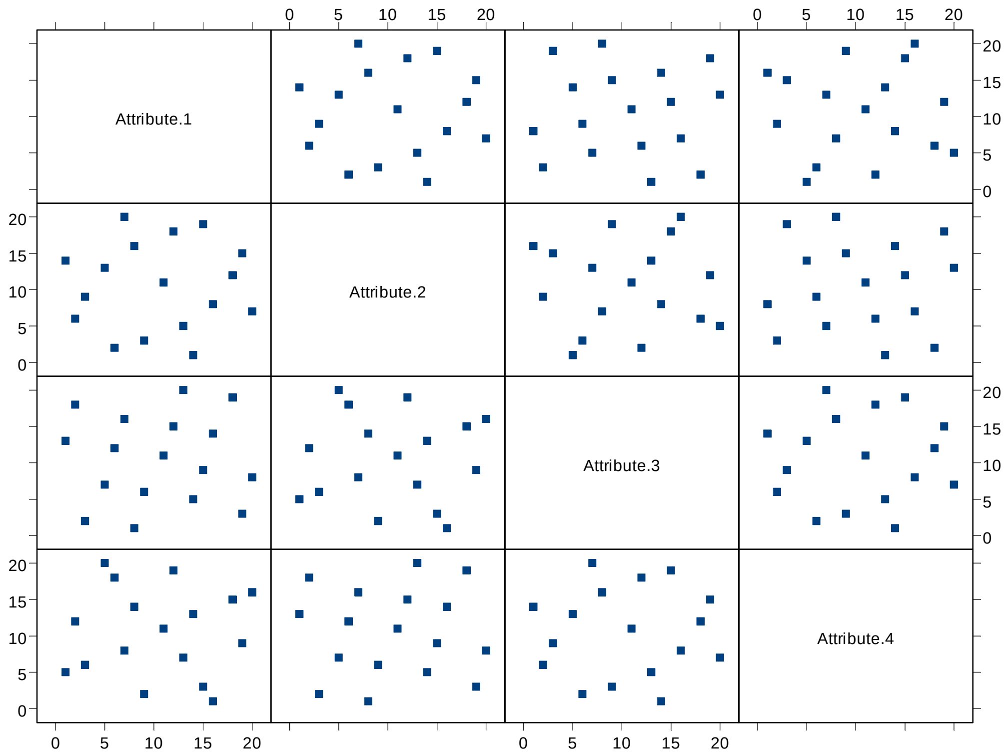


Figure 28. Scatter plot of NOLH Design (4 factors, 20 levels, 17 design points).

	Attribute 1	Attribute 2	Attribute 3	Attribute 4
Attribute 1	1			
Attribute 2	0.0176399	1		
Attribute 3	0.0004055	0.0004055	1	
Attribute 4	0.0004055	0.0004055	0.0176399	1

Table 7. Correlation matrix for NOLH design.

Utilizing our design matrix, we manually performed one replication, or 17 runs. Each run was performed for 100 time steps. This was more than ample to allow the priority lag and trigger train phenomena to emerge. As previously stated, we intentionally setup our model in a deterministic manner to enable us to compare the agent attitude response to the true response if priority lag and trigger trains were eliminated. As a result of this deterministic approach, there was no need to perform more than one replication of our design matrix in order to achieve our goal for this simulation experiment. Next, we provide these results and shed light onto the emergence of priority lag and trigger trains.

C. PRIORITY LAG AND TRIGGER TRAIN ERRORS

Table 8 displays a portion of the output collected from the execution of design point 1 from Table 6. The right side of Table 8 contains the calculated true attitudinal stances with no induced errors. The true blueness values are listed in the "TRUE" column. The left side of Table 8 contains the deterministic simulation output produced, with the simulated blueness values listed in the "ACTUAL" column. This scenario utilizes the hierarchical issue structure settings in III.B.2.d. Take note of the priorities listed; attribute 1 is the highest, followed by attribute 4, attribute 2, and then attribute 3. As well, the trigger set bounds for the S1_PF_ILT_I agent are from 200 to 300, with all triggers back to "Initial," resetting the tripped attributes to a median value of 250.

Timestep	Deterministic Simulation Results							True Results in Absence of Any Color Losses								
	Att1	Att4	Att2	Att3	ACTUAL	% Error	Behavior	Att1	Color	Att4	Color	Att2	Color	Att3	Color	TRUE
0	305	306	318	314	76	0.0%	<INITIAL>	305	6	306	4	318	2	314	1	89
1	257	314	338	330	82	7.9%	S1_Att1PositiveCC	257	0	258	0	270	0	266	0	89
2	264	322	358	346	82	7.9%	INITIAL	264	0	266	0	290	0	282	0	89
3	271	258	378	362	86	3.4%	S1_Att4PositiveCC	271	0	274	0	310	2	298	0	91
4	278	266	398	378	86	5.5%	INITIAL	278	0	282	0	270	0	314	1	92
5	285	274	418	394	86	6.5%	S1_BluenessBetween86-106	285	0	290	0	290	0	266	0	92
6	292	282	270	410	88	4.3%	S1_Att2PositiveCC	292	0	298	0	310	2	282	0	94
7	299	290	290	426	88	6.4%	INITIAL	299	0	306	4	270	0	298	0	98
8	306	298	310	442	88	10.2%	S1_BluenessBetween86-106	306	6	258	0	290	0	314	1	105
9	257	306	330	458	94	10.5%	S1_Att1PositiveCC	257	0	266	0	310	2	266	0	107
10	264	314	350	474	94	12.1%	INITIAL	264	0	274	0	270	0	282	0	107
11	271	322	370	490	94	12.1%	S1_BluenessBetween86-106	271	0	282	0	290	0	298	0	107
12	278	258	390	506	98	8.4%	S1_Att4PositiveCC	278	0	290	0	310	2	314	1	110
13	285	266	410	522	98	10.9%	INITIAL	285	0	298	0	270	0	266	0	110
14	292	274	430	538	98	10.9%	S1_BluenessBetween86-106	292	0	306	4	290	0	282	0	114
15	299	282	270	554	100	12.3%	S1_Att2PositiveCC	299	0	258	0	310	2	298	0	116
16	306	290	290	570	100	13.8%	INITIAL	306	6	266	0	270	0	314	1	123
17	313	298	310	586	100	18.7%	S1_BluenessBetween86-106	257	0	274	0	290	0	266	0	123
18	257	306	330	602	106	13.8%	S1_Att1PositiveCC	264	0	282	0	310	2	282	0	125
19	264	314	350	618	106	15.2%	INITIAL	271	0	290	0	270	0	298	0	125
20	271	322	370	634	106	15.2%	S1_BluenessBetween86-106	278	0	298	0	290	0	314	1	126
21	278	330	390	650	106	15.9%	S1_BluenessBetween106-116	285	0	306	4	310	2	266	0	132
22	285	258	410	666	110	16.7%	S1_Att4PositiveCC	292	0	258	0	270	0	282	0	132
23	292	266	430	682	110	16.7%	INITIAL	299	0	266	0	290	0	298	0	132
24	299	274	450	698	110	16.7%	S1_BluenessBetween86-106	306	6	274	0	310	2	314	1	141
25	306	282	470	714	110	22.0%	S1_BluenessBetween106-116	257	0	282	0	270	0	266	0	141
26	257	290	490	730	116	17.7%	S1_Att1PositiveCC	264	0	290	0	290	0	282	0	141
27	264	298	510	746	116	17.7%	INITIAL	271	0	298	0	310	2	298	0	143
28	271	306	530	762	116	18.9%	S1_BluenessBetween86-106	278	0	306	4	270	0	314	1	148
29	278	314	550	778	116	21.6%	S1_BluenessBetween106-116	285	0	258	0	290	0	266	0	148
30	285	322	570	794	116	21.6%	S1_BluenessBetween116-127	292	0	266	0	310	2	282	0	150
31	292	258	590	810	120	20.0%	S1_Att4PositiveCC	299	0	274	0	270	0	298	0	150
32	299	266	610	826	120	20.0%	INITIAL	306	6	282	0	290	0	314	1	157
33	306	274	630	842	120	23.6%	S1_BluenessBetween86-106	257	0	290	0	310	2	266	0	159
34	313	282	650	858	120	24.5%	S1_BluenessBetween106-116	264	0	298	0	270	0	282	0	159
35	320	290	670	874	120	24.5%	S1_BluenessBetween116-127	271	0	306	4	290	0	298	0	163
36	257	298	690	890	126	22.7%	S1_Att1PositiveCC	278	0	258	0	310	2	314	1	166
37	264	306	710	906	126	24.1%	INITIAL	285	0	266	0	270	0	266	0	166

Table 8. Design point #1 deterministic output comparison to true attitudinal stance calculations. [Best viewed in color]

Once an attribute within the hierarchical issue structure trips the upper bound, the agent should enter the appropriate color change alternate behavior and receive a weighted color splash for effective influence experienced. Each gray-shaded cell indicates when this alternate behavior entry should occur per attribute. As we show under the true results portion of Table 8, each gray cell shown is accompanied by a green cell, indicating the application of the respective weighted color splashes, followed by a return to "Initial." In other words, we should not see consecutive gray-shaded cells. This is not the case for the simulation output.

Time steps 33 to 36 in Table 8 provide a good example of the synergistic effect of priority lag and trigger trains. At time step 33, attributes 1, 2, and 3 have crossed the trigger set upper bound. However, attribute 1 does not trigger into an alternate behavior for a color splash until time step 36. This is a result of the three-step trigger train returning the agent to the proper attitudinal state. Remember, as discussed in III.D.1.e, color triggers always take precedence over attribute triggers. Therefore, during each time step, the model checks the current attitudinal stance of the agents and then ensures the agents are sent to their proper color bin, as shown in the social network caption in Figure 27. While this is occurring, all effective influences are still accumulating. Furthermore, notice that attribute 4 has an attribute setting of 890 at time step 36. However, because it is the lower priority attribute, it does not trigger and all the effective influence injected into the hierarchical issue structure with respect to attribute 4 goes unrewarded. In fact, attribute 4 never registers any attitudinal splashes for the entire run, even though it reaches the maximum of 1,000. The longer the trigger trains, which are caused by departures from initial attitudinal stances, the worse the priority lag. Therefore, the inherent priority lag associated with a time-step model is amplified by our trigger set modeling methodology.

The "% Error" column in Table 8 lists the calculated percent errors per time step for this design point. As we can see, the errors are quite significant and accumulate quickly. We consolidated the data from the replication of our design matrix to determine the mean percent error experienced per time step using our trigger set modeling methodology. The results are graphically provided in Figure 29. The maximum percent error of 33% occurred at time step 73, with an overall mean percent error of 24% with respect to attitude representation.

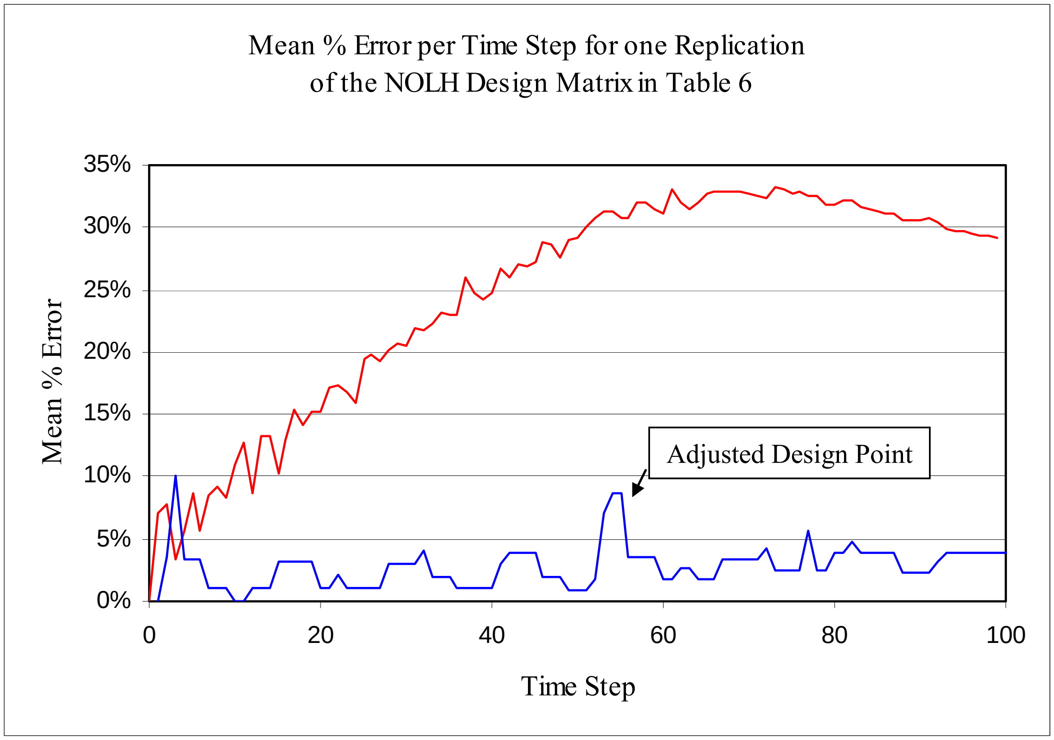


Figure 29. Attitude representations mean percent error per time step due to priority lag and trigger train color losses.

Insights gleaned from the data provided in Table 8 indicate that utilizing smaller attribute changer magnitudes to reduce attitudinal shifts, as well as distributing the lesser magnitudes towards the higher priority attributes to minimize priority lag, should greatly reduce these errors. We performed one run utilizing a design point listed in the same format shown in Table 6: 1, 4, 5, 2. Notice that the lesser levels are assigned to the higher priority attributes—attribute 1 and attribute 4. As well, all levels are less than or equal to 5. These settings help prevent the higher priority settings from dominating the trigger set and reduce the potential for attitudinal departures from "Initial." The results from this run are also displayed in Figure 29. The mean percent error per time step was reduced to 3% for this individual run. This verifies our understanding of causal errors from priority lag and trigger trains. Although these adjustments provide an effective fix, they are not practical in any way and greatly restrict flexibility. We recommend modifications in Section E, which would eliminate trigger trains altogether and, subsequently, help minimize the effects of priority lag.

D. SOCIAL NETWORK INFLUENCE TRANSFER ERROR

As discussed in III.D.1.e, we continually reset agents' tripped attributes to the median value within the fixed bounds in their respective "Initial" states to ensure the tripped attributes do not continually dominate the trigger sets. This resetting of attributes prevents accurate attribute value tracking and establishes inaccurate differentials, which are subsequently transferred throughout the social network via the attached attribute changers. We constructed another simplified model and experimental design to investigate and quantify the effect of these inaccurate social network influence transfers. Due to the parallel effort of this research, the details on the model construction and experimental design utilized are provided in CDR Seitz's thesis.[30] In this section, we provide only a brief discussion of the results found and insights gleaned.

The model utilized is very similar to the one shown in Figure 27. The only difference is the addition of one more agent that is networked with the targeted agent. For example, the HN_PM_PG targets the S1_PF_ILT_I agent with perceived good influence, and then the effect of the attitudinal shift on the S1_PF_ILT_HN agent is transferred via our social networking methodology to the additional networked agent. This additional agent receives influence only through the social network link and experiences no global or nonglobal actor actions.

Once again, all settings for this simulation experiment enabled deterministic output to be collected for comparison to the true attitudinal response. As well, we targeted only one issue within the hierarchical issue structure vice all four, as we did in the priority lag and trigger train color loss experiment. This eliminated the possibility of priority lag color losses and prevented them from convoluting the social network

[30] CDR Thorsten Seitz, German Navy, "Representing Urban Cultural Geographies in Stability Operations, Analysis of a Social Network Representation in Pythagoras," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2008.

influence transfer errors. The results for the first run are displayed in Figure 30 and provide great insight into the significant error resulting from resetting our attributes. The targeted agent refers to the recipient of the nonglobal action and the networked agent refers to the agent receiving influence solely through the social network.

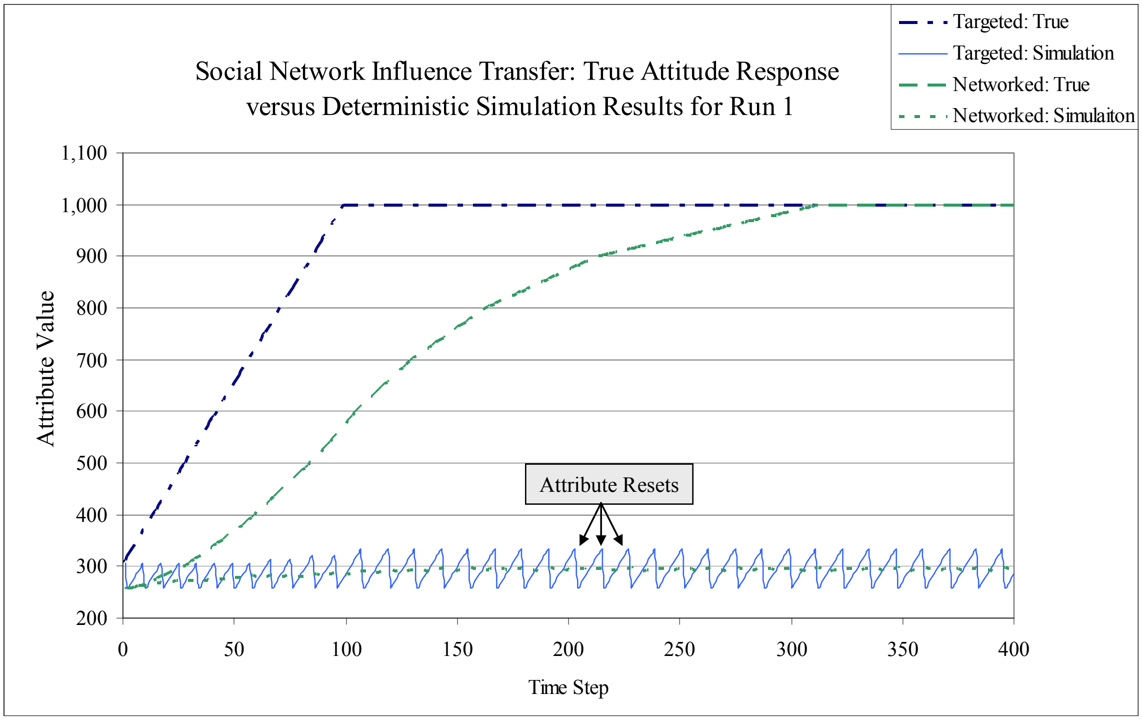


Figure 30. Graphical display of the social network influence transfer deficiencies resulting in inaccurate attitude representations. [Best viewed in color]

The targeted agent is receiving positive influence during each time step and it should accumulate linearly until it reaches the maximum limit of 1,000, as shown in Figure 30. Then, each time step, the calculated relative differential between the targeted agent and the networked agent should gradually pull the networked agent in a positive direction. The rate of this influence is dependent on the percentage set in the network attribute changer and the attribute vulnerability settings for the networked agent. As we can see in Figure 30, due to the continuous resets back to the median value, this is not happening. In fact, each time the targeted agent is reset to the median value of 250, the differential becomes negative. Hence, the targeted agent is actually pulling the networked agent in a negative direction, even though the only influence experienced has been positive. This prevents the networked agent from ever crossing the trigger set upper bound and receiving any color splashes. As well, it reveals the reason why we were seeing the unpredictable responses that led us to further investigate and understand our model.

The mean percent errors per time step, calculated from the simulation experiment presented in CDR Seitz's thesis, are presented in Figure 31. As illustrated, the required resets utilized in our trigger set modeling methodology result in attitude representation errors greater than 70%.

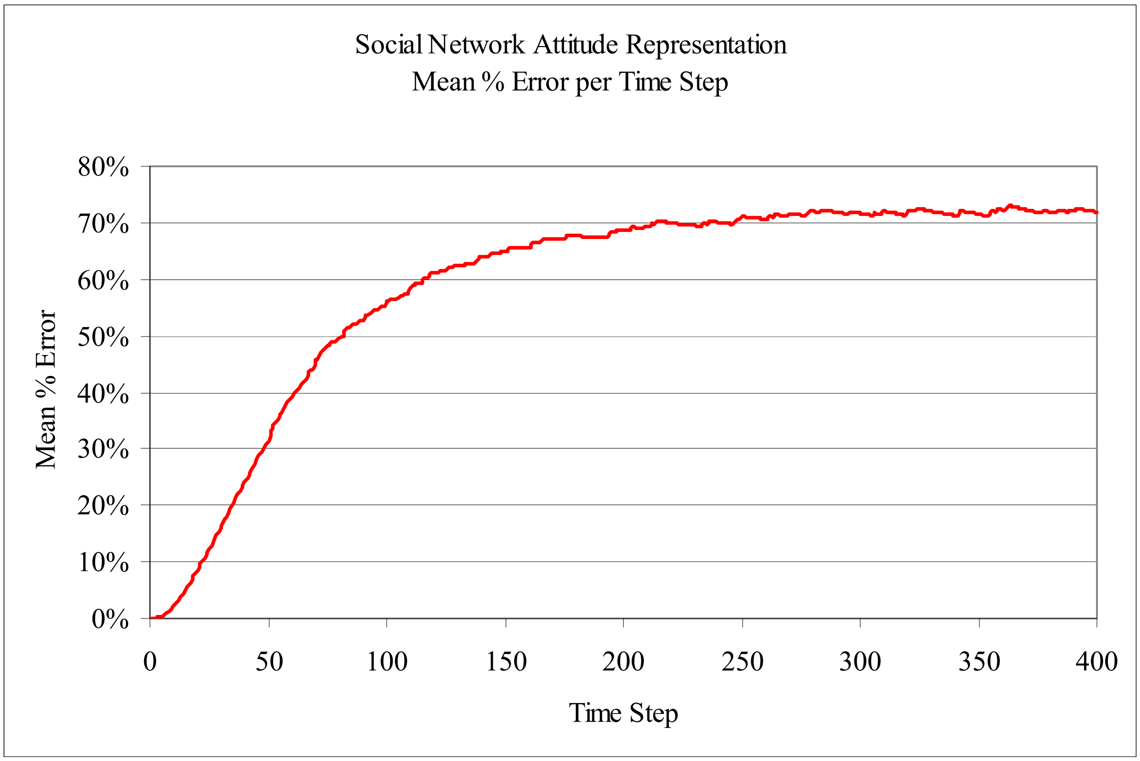


Figure 31. Attitude representation mean percent error per time step, due to inaccurate attribute differentials between networked agents.

A few other insights were gleaned from this simulation experiment as well. First, priority lag and trigger train color loss can, in fact, mask social network influence transfer error. Priority lag and trigger trains prevent agents from triggering even when the agents have crossed the upper bounds, but this is beneficial to the social network transfer because it actually allows the accurate attribute differentials to exist for longer periods of time. Essentially, preventing triggers also minimizes resets, which is good for the social network influence transfers. Therefore, the error displayed in Figure 31 would actually be larger if trigger trains could be removed along with the priority lag. Second, due to continuous resets, negative influence transfers can occur even when only positive influences are introduced to the civilian populace. Third, the amount of influence transfer throughout the social network is inversely proportional to the magnitude of influence exerted on the civilian populace. The more influence exerted on an agent, the quicker the agent triggers and resets; these resets reduce attribute differentials and, hence, less influence transfer occurs. Conversely, the less influence exerted on an agent, the less the agents trigger and reset; lesser resets maintain attribute differentials for longer periods and result in more influence transfer.

Next, we provide our recommended changes to Pythagoras 2.0.0 for minimizing the attitude representation errors due to priority lag, trigger trains, and the inaccurate social network influence transfers resulting from continuous resets within our trigger set methodology.

E. RECOMMENDATIONS

The first recommendation focuses on eliminating trigger trains. The further agents depart from their "Initial" attitudinal states, the longer the trigger trains every time the agents are sent back to "Initial." Modifying the color triggers by incorporating a drop-down list with user-defined color bin entries, along with the ability to enter alternate behaviors from within the list, would eliminate trigger trains altogether. Agents can possess only one color at a time; thus, creating a binned list using true and false logic is quite possible. The current set of six color triggers in Pythagoras could be condensed down to three: "Red Color Bins," "Green Color Bins," and "Blue Color Bins" triggers. As an example, if there were three possible networks within a scenario, then three color bins could represent these networks in the following manner:

<u>Trigger Page</u>:
Blueness Bins: (List should have capabilities for up to 25 entries)

-If blueness ≥ 0 and ≤ 120:		Alternate Behavior:	0_120bin
-If blueness ≥ 121 and ≤ 220:		Alternate Behavior:	121_220bin
-If blueness ≥ 221 and ≤ 255:		Alternate Behavior:	221_255bin

Hence, each time an agent returns to "Initial," Pythagoras searches through the list for the only true matched bin with the current agent attitudinal stance. Then, the selected true bin from the list will send the agent to the entered and accurate alternate behavior in only one time step, without having to trigger train to get the agent there. Notice that the list entries are greater than and equal to and less than or equal to for each list entry. This is also different than the current color triggers in Pythagoras, which uses separate triggers for greater than or less than entries.

Our second recommendation concerns priority lag and the social network influence transfer problem. The elimination of trigger trains automatically helps reduce the effect of priority lag, because attributes will not continue accumulating while the simulation wastes several time steps to place the agent in the proper color bin. Thus, the lower priority attributes will not be dominated as easily by the higher priority attributes. Inherent to a time step model, priority lag cannot be completely eliminated. However, we believe some modifications may help further minimize the chances of a dominating attribute within the trigger sets.

These modifications include two additional capabilities within Pythagoras, along with a modification to the current attribute trigger setup. First, color change capabilities should be added to attribute changers. Attribute changers could then assume the color change functionality currently placed with weapons. Because attribute changers can be attached to weapons, the current color weapon capabilities could be removed. Second, the option to attach attribute changers to triggers should be added. Hence, when a trigger with an attached attribute changer is tripped, the attribute changer is activated. It is imperative to possess control over the number of time steps the attached attribute changer is activated for as well. These added functionalities would create an "auto-splash" capability that would remove our current methodology requirement to use the "All Is Well" side change property, as discussed in III.D.3. This, in turn, introduces added capability for economic feedback and revives the possible implementation of embedded trigger sets, if deemed practical. Lastly, the following 20 attribute trigger options should be added to Pythagoras:

Trigger Page:
-Attribute 1,....,10 increases by: User input # Alternate Behavior: User entry
-Attribute 1,....,10 decreases by: User input # Alternate Behavior: User entry

The input number within these modified attribute triggers represents the desired fidelity of the model. Most importantly, because we are not forced to enter trigger set bounds, there is never a need to reset the attributes. These changes enable the social network influence transfer to operate using accurate differentials.

With these three modifications to Pythagoras, the modeling methodology described in Chapter III would be greatly improved. The modifications would allow us to attach color change-capable attribute changers to each of the modified attribute triggers. Each time an attribute trigger trips, these modified attribute changers will automatically splash the agents with their respective weighted color changes based off their hierarchical issue structures. As well, with the added ability to enter alternate behaviors from tripped triggers, the agents could immediately be sent back to "Initial." As discussed in our first recommendation, the modified color triggers with drop-down lists will immediately send agents to their proper color bin alternate behavior and avoid any trigger trains. The flow would be as follows and is illustrated in Figure 32:

- An attribute increases or decreases by the input value and the trigger trips.
- The appropriate color splash is immediately applied.
- The agent is sent to an alternate behavior: We input "Initial."
- In "Initial," Pythagoras checks which color bin is true and sends the agent to appropriate color bin alternate behavior in one time step (which places the agents in the proper networks with appropriate participation distributions).
- The process starts over again.

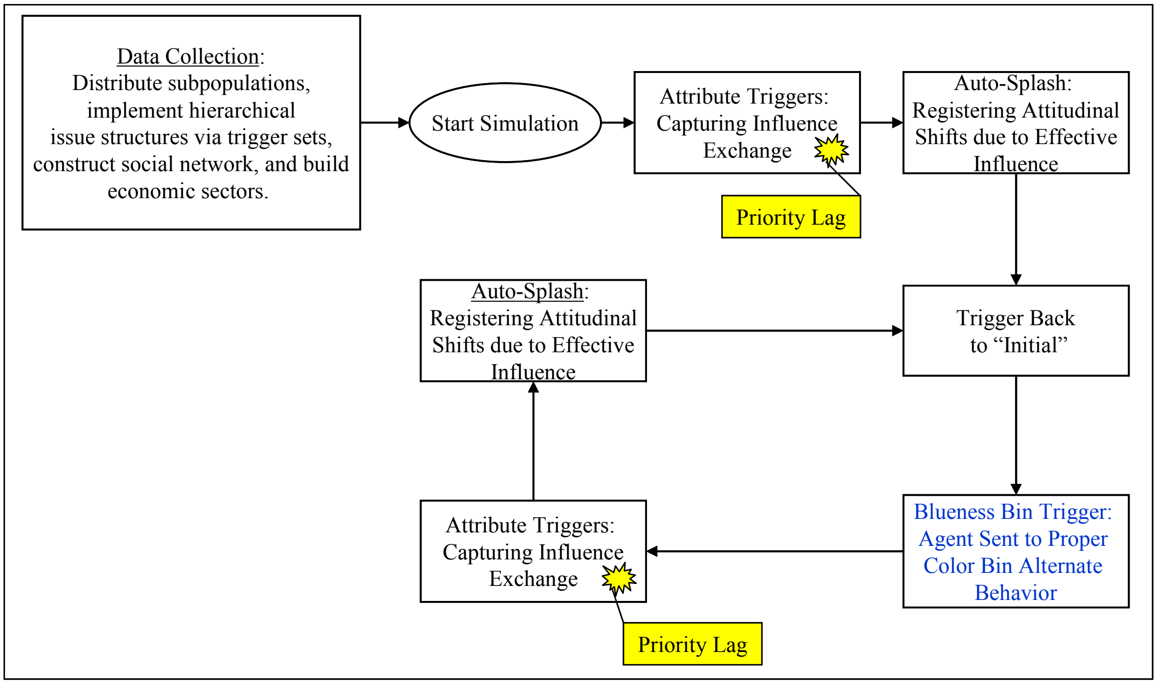


Figure 32. Improved modeling methodology flow diagram.

We believe these modifications would help minimize priority lag and eliminate trigger trains and the social network influence transfer problems.

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V. CONCLUSIONS

A. RESEARCH SUMMARY

This research focused on formulating effective modeling methodologies within the Pythagoras 2.0.0 modeling environment for a specific analytic social theory model suite. This model suite comprised an attitude effect model, a social network model, and an economic insurrection model. Through design of an abstract scenario within the Pythagoras 2.0.0 modeling environment, we provide a detailed modeling methodology that captures, to the best of our abilities and to the maximum extent possible, the characteristics described within each analytic social theory model. Limitations encountered and their negative impacts on attitude representation are documented, along with recommendations for modifications to the Pythagoras 2.0.0 simulation tool. The implementation of these modifications will minimize attitude representation error and enable this analytic social theory model suite to be modeled within Pythagoras 2.0.0. As such, Pythagoras 2.0.0 will offer analysts a stand-alone simulation tool capable of investigating HBR, and specifically concerning the ultimate goal for the RUCG team, the complex interactions of a civilian populace experiencing stability operations within an IW environment.

B. RESEARCH QUESTIONS

The objective for this research was to determine and provide the following:

- Can a representative modeling framework for the RUCG analytic social theory model suite be implemented with a stand-alone simulation tool?
- Provide detailed documentation of all successful and unsuccessful modeling methodology mappings, as well as recommendations of enhancements with respect to the simulation tool of choice.

Due to limitations within Pythagoras 2.0.0, the entirety of the RUCG analytic social theory model suite could not be effectively implemented within it. Although these three analytic models are quite simple individually, we found our attempt to implement all three simultaneously proved to be quite difficult, and resulted in modification recommendations necessary to accomplish our objective. Although Pythagoras 2.0.0 has recently undergone improvements to provide social networking capabilities, there still exist many functions that are specific only to conventional combat. This is not surprising, as Pythagoras is a combat model; however, if it is planned for utilization in the HBR realm, further upgrades are needed to remove and/or minimize existing errors in attitude representation.

The detailed modeling methodologies we developed for capturing the majority of the characteristics within the RUCG analytic social theory model suite are provided in Chapter III, to include specific and detailed limitations encountered and associated recommendations for improvements. In Chapter IV, we provide an in-depth analysis of three specific sources of attitude representation errors discovered during our research: priority lag color losses, trigger train color losses, and inaccurate social network transfer errors. Next, we provide tabulated summaries for limitations encountered and associated recommendations for each analytic social theory model presented in Chapter III and Chapter IV.

1. Limitations and Recommendations

The three models presented in Chapter II are relatively simple analytic models that one may think elementary to implement into a stand-alone simulation tool. Individually, these models are much easier to effectively implement. However, due to the nature of our quest in HBR within a combat model, the required workarounds necessary to simultaneously implement all three models and capture nonstandard combat behaviors quickly ran out. Hence, even though capabilities existed within Pythagoras to effectively model certain characteristics, the use of these capabilities caused malfunctions in methodologies already implemented for one of the other three models. This forced trade-off decisions to be made on the importance of the competing methodologies. It follows then that some of the limitations presented are not listed due to a lack of capability within Pythagoras, but due to a lack of capability in conjunction with other required methodologies. In other words, these limitations exist due to a single function in Pythagoras that was needed for more than one characteristic. Therefore, within the tabulated summaries provided, some limitations appear more than once, depending on their effect concerning necessary model mappings across the entire analytic social theory model suite.

Lastly, several of the limitations encountered affect all three modeling methodologies and, thus, we list them within each table of summarized limitations and recommendations. Limitation listings followed with an asterisk (*) denote major limitations and signify those limitations that must be fixed in order to enable Pythagoras 2.0.0 to serve as a stand-alone simulation tool capable of capturing the characteristics of the entire RUCG analytic social theory model suite. This does not suggest that the other limitations are not important, but if the annotated limitations go unfixed, then Pythagoras 2.0.0 will remain incapable of HBR in the context of our research efforts.

a. Attitude Effect Model

The results in Table 9 briefly summarize the limitations encountered and associated recommendations resulting from our research efforts with respect to implementation of the attitude effect model within the Pythagoras 2.0.0 modeling environment. The detailed presentations are provided in Chapter III.C and Chapter IV.

Limitations	Recommendations
No direct link between color and attributes forces us to implement our trigger set methodology. This, in turn, induces three significant sources of attitude representation error: priority lag color loss, trigger train color loss, and inaccurate social network transfer errors.*	Refer to recommendations for the specific error sources listed.
Attribute range from 0 to 1,000 and color range from 0 to 255. Only integer inputs for these characteristics causes automatic error from conversion.	Remove integer restrictions or match attribute and color ranges.
Absence of link between sidedness differentials and attribute vulnerability settings.	Implement capability to compute temporary attribute vulnerabilities based on sidedness differentials. Differentials result in pseudo-increases and decreases of input attribute vulnerability settings, depending on the signs of the differentials.
No capability for direct perception control; cannot enter a probability that an action is perceived as good or bad.	Add perception settings to attribute changers. Set the default to perceived good, with optional entry for probability that actions are perceived as bad. Utilize a

Limitations	Recommendations
	random draw based off the entered probability to determine the sign of the action.
No direct capability for memory implementation; instantaneous or distributed.	If determined the cost in complexity is worth the potential gain for this capability addition, the manner of implementation is up to the developers.
Absence of a link between leadership settings and vulnerability settings.	Implement capability to compute temporary attribute vulnerabilities based on leadership differentials. Differentials result in pseudo-increases and decreases of input attribute vulnerability settings, depending on the signs of the differentials.
Current color trigger setup induces trigger train color losses.*	Incorporate a drop-down list with user-defined color bin entries and add the ability to enter alternate behaviors from each list entry. Utilize true/false logic each time an agent enters an alternate behavior with the color bin entry activated. Each list entry must contain greater than and equal to and less than and equal to color entry options.
Priority lag induces significant attitude representation errors.*	Add color change capabilities to attribute changers and the ability to attach attribute changers to triggers. This creates an "auto-splash" capability, reviving embedded trigger trees and allowing the implementation of economic feedback. Lastly, add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model.
Inaccurate social network influence transfers cause significant attitude representation errors.*	Add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model. These modified attribute triggers eliminate the need for resetting attributes after entries into alternate behavior trigger sets, ensuring attribute differentials maintain accuracy and enable proper influence transfer across the social network.
Note: Each (*) annotates a major limitation that must be fixed in order to enable Pythagoras 2.0.0 to serve as a stand-alone simulation tool capable of capturing the characteristics of the entire RUCG analytic social theory model suite.	

Table 9. Attitude effect modeling methodology limitations and associated recommended modifications for Pythagoras 2.0.0.

b. *Social Network Model*

The tabulated results in Table 10 briefly summarize the limitations encountered and associated recommendations resulting from our research efforts with respect to implementation of the social network model within the Pythagoras 2.0.0 modeling environment. The detailed presentations are provided in Chapter III.D and Chapter IV.

Limitations	Recommendations
No direct link between color and attributes forces us to implement our trigger set methodology. This, in turn, induces three significant sources of attitude representation error: priority lag color loss, trigger train color loss, and inaccurate social network transfer errors.*	Refer to recommendations for the specific error sources listed.
Attribute range from 0 to 1,000 and color range from 0 to 255. Only integer inputs for these characteristics causes automatic error from conversion.	Remove integer restrictions or match attribute and color ranges.
Cannot implement embedded triggers, even if deemed practical, due to the lack of ability for agents to "auto-splash."*	Add color change capabilities to attribute changers and the ability to attach attribute changers to triggers. This creates an "auto-splash" capability, reviving embedded trigger trees and allowing the implementation of economic feedback.
Due to forced bound entries for attribute triggers, even if an "auto-splash" was available, embedded triggers grow exponentially.	Add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model.
Absence of a link between leadership settings and vulnerability settings.	Implement capability to compute temporary attribute vulnerabilities based on leadership differentials. Differentials result in pseudo-increases and decreases of input attribute vulnerability settings, depending on the signs of the differentials.
Current color trigger setup induces trigger train color losses.*	Incorporate a drop-down list with user-defined color bin entries and add the ability to enter alternate behaviors from each list entry. Utilize true/false logic each time an agent enters an alternate behavior with the color bin entry activated. Each list entry must contain greater than and equal to and less than and equal to color entry options.
Priority lag induces significant attitude representation errors.*	Add color change capabilities to attribute changers and the ability to attach attribute changers to triggers. This

Limitations	Recommendations
	creates an "auto-splash" capability, reviving embedded trigger trees and allowing the implementation of economic feedback. Lastly, add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model.
Inaccurate social network influence transfers cause significant attitude representation errors.*	Add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model. These modified attribute triggers eliminate the need for resetting attributes after entries into alternate behavior trigger sets, ensuring attribute differentials maintain accuracy and enable proper influence transfer across the social network.
Note: Each (*) annotates a major limitation that must be fixed in order to enable Pythagoras 2.0.0 to serve as a stand-alone simulation tool capable of capturing the characteristics of the entire RUCG analytic social theory model suite.	

Table 10. Social network modeling methodology limitations and associated recommended modifications for Pythagoras 2.0.0.

c. Economic Insurrection Model

The tabulated results in Table 11 briefly summarize the limitations encountered and associated recommendations resulting from our research efforts with respect to implementation of the economic insurrection model within the Pythagoras 2.0.0 modeling environment. The detailed presentations are provided in Chapter III.E and Chapter IV.

Limitations	Recommendations
Limited control of attribute changers attached to terrain pieces.	Incorporate ability to manipulate fire rate for attached attribute changer or allow weapons with attached attribute changers to be attached to terrain pieces.
Limited ability to move agents to pieces of terrain.	Incorporate ability to assign identification numbers to user built pieces of terrain. Add movement desire option to allow entry of the identification numbers.
Cannot implement probability of successful insurrection due to methodology requirements to splash agents; lack of "auto-splash" capability.*	Incorporate "auto-splash" capabilities with the addition of color change capabilities to attribute changers and the ability to attach attribute changers to triggers.
Restricted "Resource" capabilities concerning HBR in an IW environment. "Resource" settings are applicable only for simulating conventional combat.	Remove the restriction of resource supply/resupply between "other than enemy." Add movement desires allowing movement towards enemies needing/giving resources.
Current color trigger setup induces trigger train color losses.*	Incorporate a drop-down list with user-defined color bin entries and add the ability to enter alternate behaviors from each list entry. Utilize true/false logic each time an agent enters an alternate behavior with the color bin entry activated. Each list entry must contain greater than and equal to and less than and equal to color entry options.
Priority lag induces significant attitude representation errors.*	Add color change capabilities to attribute changers and the ability to attach attribute changers to triggers. This creates an "auto-splash" capability, reviving embedded trigger trees and allowing the implementation of economic feedback. Lastly, add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model.
Inaccurate social network influence transfers cause significant attitude representation errors.*	Add attribute trigger options that do not require bounded entries. These trigger options should be triggered off increments and decrements, which represent the desired fidelity of the model. These modified attribute triggers eliminate the need for resetting attributes after entries into alternate behavior trigger sets, ensuring attribute differentials maintain accuracy and enable proper influence transfer across the social network.
Note: Each (*) annotates a major limitation that must be fixed in order to enable Pythagoras 2.0.0 to serve as a stand-alone simulation tool capable of capturing the characteristics of the entire RUCG analytic social theory model suite.	

Table 11. Economic insurrection modeling methodology limitations and associated recommended modifications for Pythagoras 2.0.0.

C. FOLLOW-ON RESEARCH

The following list includes possible extensions of this research, assuming the recommended modifications to the major limitations listed in Tables 9, 10, and 11 are funded and implemented in the Pythagoras modeling environment:

- Review the modifications implemented into Pythagoras 2.0.0 and reevaluate its ability to accommodate the RUCG analytic social theory model suite.
- Leverage the MCCDC IW study data acquisition process for data collection to be utilized for construction of a Southwest Asia scenario. This data acquisition process is founded on intensive cultural research and an interview process with subject matter experts (SME) to build narrative paradigms for regions of interest. These interviews are designed to develop quantitative measures of influence across the target populace segment demographics utilizing semantic differentials.[31]
- Evaluate how readily the resulting data from the MCCDC IW data acquisition process traces into the Pythagoras modeling environment.
- Perform a sensitivity analysis on the attitudes of the civilian populace to the data collected via the MCCDC IW data acquisition process, as well as for a range of Diplomatic, Informational, Military, Economic (DIME) and insurgent actions.
- Construct a design of experiment (DOE) in order to explore for emerging behaviors and complex interactions in efforts to answer the following questions:
    - What are the most critical factors in determining the attitude of a civilian populace?
    - How does the social network structure impact the ability of the blue forces to affect the attitude of the civilian populace?
    - How do PMESII factors interact to influence the attitude of the civilian populace?
    - Does the composition of the civilian populace impact the effectiveness of blue force actions and/or the perceptions of these actions?

[31] LT Robin Marling, USMC, "USMC Irregular Warfare Project," PowerPoint presentation, MCCDC, December 2007, slides 1-66.

APPENDIX A: ATTITUDE EFFECT MODEL WORKING PAPER

The following model is a working paper within the Operations Research Department at NPS. It served as one of three models within the TRAC Monterey RUCG project team analytic social theory model suite. For our research efforts, this model provided methods for quantifying attitudinal changes within a civilian populace, subject to competing forces striving to win their hearts and minds.

A Model for the Effect of Host Nation/Insurgency Operations on a Population

By

P. A. Jacobs
D. P. Gaver
M. Kress
R. Szechtman

1. Model Overview

There are K *actors* —examples of actors are a host nation, group of insurgents, the outside stability forces, the militias, outside military forces that do not support the host nation, etc.

There are S *subpopulations* (homogenous groups of people) — examples of subpopulations are a tribe whose members believe in the same religion and who reside in a particular location; the (sub)collection of people who attend a particular mosque and tend to share common cultural features or in a certain neighborhood in a major city.

The actors take actions against each other and against the subpopulations; examples of actions are assassinations, job creation in a location, maintenance of police presence in a neighborhood, etc. The subpopulations do not take actions. The *effect* of an actor's action has a duration during which the subpopulations perceive the action as being good (helpful) or bad (hurtful). The result of the subpopulations' perceptions of the actions may be changes of their attitude towards certain actors.

2. A Specific Model

There are S subpopulations. There are two actors—the host nation (H) and the insurgency (I)—and S subpopulations, $s \in \{1, 2..., S\}$, each either supports H or I. A supporter of H (respectively I) opposes I (respectively H). Each actor generates actions; in the present model there is only one kind of action for each actor; the actions themselves are not labeled as good or bad. However, each action by an actor is perceived by a subpopulation as being good or bad; degrees of "goodness" and "badness" are not represented in the current model. The perception of each actor's actions by a subpopulation influences the attitude of the subpopulation towards the actor. The attitudinal effect of an action on subpopulation s has a limited duration; the actions affect attitudes in a subpopulation through media reporting, word of mouth and personal exposure to the effect of the action such as destruction/repair of local infrastructure, job loss/creation, etc. An action is called *active* at time t if it is still influencing subpopulation attitude (pro/anti H, etc.) at time t. This model assumes that an entire subpopulation responds simultaneously and homogenously to actions and their effects.

Let $G_H(s,t) \geq 0$, (respectively $B_H(s,t) \geq 0$), be the mean number of active H-actions perceived as good, (respectively bad), by subpopulation s at time t. Let $G_I(s,t) \geq 0$, (respectively $B_I(s,t) \geq 0$), be the mean number of active I-actions perceived as good, (respectively bad), by subpopulation s at time t.

Model Premise:

Active H-actions perceived as good by subpopulation s and active I-actions perceived as bad by subpopulation s encourage subpopulation s to support H. Active H-actions perceived as bad by subpopulation s and active I-actions perceived as good by subpopulation s encourage subpopulation s to support I.

Let $p_s(t)$ be the measure of subpopulation s support for H at time t; $0 \leq p_s(t) \leq 1$. The measure of subpopulation s support for I is $1 - p_s(t)$ If $p_s(t)$=1 then subpopulation s strongly supports H; if $p_s(t)$=0 then subpopulation s strongly supports

I. Let $y_s(t) = \log\left[\frac{p_s(t)}{1-p_s(t)}\right]$, the log odds of the measure that population s supports H at time t; $y_s(t) \in (-\infty, \infty)$; large positive values reflect support for H and negative values reflect support for I. Let $\underline{y}(t) = (y_1(t), \ldots, y_S(t))$, the vector of log odds for all the subpopulations. This vector represents the subpopulations' attitudes towards H and I.

Model 1:

Parameters

Constant rate at which H initiates actions	λ_H
Constant rate at which I initiates actions	λ_I
The probability an H-action is perceived as good (respectively as bad) by subpopulation s at time t. This probability may depend on the attitude of other subpopulations.	$0 \le \gamma_H(s, \underline{y}(t)) \le 1$ (respectively $1-\gamma_H(s, \underline{y}(t)) \equiv \overline{\gamma}_H(s, \underline{y}(t))$)
The probability an I-action is perceived as good (respectively as bad) by subpopulation s at time t.	$0 \le \gamma_I(s, \underline{y}(t)) \le 1$ (respectively $1-\gamma_I(s, \underline{y}(t)) \equiv \overline{\gamma}_I(s, \underline{y}(t))$)
The mean time an H-action perceived by subpopulation s as good (respectively bad) remains active with respect to subpopulation s.	$1/\mu_{HG}(s) \ge 0$ (respectively $1/\mu_{HB}(s) \ge 0$)
The mean time an I-action perceived by subpopulation s as good (respectively bad) remains active with respect to subpopulation s.	$1/\mu_{IG}(s) \ge 0$ (respectively $1/\mu_{IB}(s) \ge 0$)
Coefficient that translates the number of active H-actions perceived as good (respectively bad) by subpopulation s into attitude change in that subpopulation; (see Eq. 2).	$\xi_{HG}(s, \underline{y}(t)) \ge 0$ (respectively $\xi_{HB}(s, \underline{y}(t)) \ge 0$)
Coefficient that translates the number of active I-actions perceived as good (respectively bad) by subpopulation s into attitude change in that subpopulation;(see Eq 2).	$\xi_{IG}(s, \underline{y}(t)) \ge 0$ (respectively $\xi_{IB}(s, \underline{y}(t)) \ge 0$)
Initial attitude of subpopulation s towards H	a_s

Equations for the Mean Number of Active Actions:

$$\underbrace{G_H(s,t+h)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = \underbrace{G_H(s,t)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t}}} + \underbrace{\lambda_H \gamma_H(s; \underline{y}(t))h}_{\substack{\text{Mean number}\\ \text{of actions by H}\\ \text{that are perceived}\\ \text{as good by}\\ \text{subpopulation s}\\ \text{that occur during}\\ \text{during time (t,t+h]}}} - \underbrace{\mu_{HG}(s) G_H(s,t)h}_{\substack{\text{Mean number of}\\ \text{actions by H that}\\ \text{are perceived as}\\ \text{good by subpopulation s}\\ \text{that stop being active}\\ \text{(are forgotten)}\\ \text{during (t, t+h]}}} \qquad (1a)$$

$$\underbrace{B_H(s,t+h)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{bad by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = B_H(s,t) + \lambda_H \overline{\gamma}_H\left(s;\underline{y}(t)\right)h - \mu_{HB}(s)B_H(s,t)h \tag{1b}$$

$$\underbrace{G_I(s,t+h)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{I-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = G_I(s,t) + \lambda_I \gamma_I\left(s;\underline{y}(t)\right)h - \mu_{IG}(s)G_I(s,t)h \tag{1c}$$

$$\underbrace{B_I(s,t+h)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{I-actions}\\ \text{perceived as}\\ \text{bad by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = B_I(s,t) + \lambda_I \overline{\gamma}_I\left(s;\underline{y}(t)\right)h - \mu_{IB}(s)B_I(s,t)h \tag{1d}$$

Example initial conditions: $G_H(s,0)=0, B_H(s,0)=0, G_I(s,0)=0, B_I(s,0)=0$ for $s \in \{1,2,...,S\}$.

Example for γ_H and γ_I:

$$\gamma_H\left(s,\underline{y}(t)\right) = p_s(t); \gamma_I\left(s,\underline{y}(t)\right) = 1 - p_s(t). \tag{1e}$$

In this example the more support subpopulation s has for H (respectively I) the more likely it is to perceive H-actions as good (respectively bad) and I-actions as bad (respectively good).

The measure of subpopulation s support for H at time 0 is $y_s(0) = a_s$. The constant a_s represents the basic support of sub-population s for H; if a_s is large and positive the basic support for H is strong; if a_s is negative then the basic support for H is weak.

The Equation for Subpopulation Attitude Changes.

$A_s(t)$ is a measure of the attitude change of subpopulation s towards the actors H and I at time t with respect to its basic attitude measure a_s. $A_s(t)$ is a function of the subpopulation's perceptions of the actions still in effect and the current attitudes $\underline{y}(t)=\left(y_1(t),...,y_S(t)\right)$ of the other subpopulations. The subpopulation s has a basic attitude towards H measured by a_s.

For positive constants $\xi_{HG}\left(s,\underline{y}(t)\right),\xi_{HB}\left(s,\underline{y}(t)\right),\xi_{IG}\left(s,\underline{y}(t)\right),\xi_{IB}\left(s,\underline{y}(t)\right)$ the change in the attitude of subpopulation s due to active actions and the attitudes of other subpopulations evolves as

$$
\begin{aligned}
\underbrace{A_s(t+h)}_{\substack{\text{Attitude}\\ \text{towards H}\\ \text{at time t+h}\\ \text{due to}\\ \text{active actions}}} = {} & \underbrace{A_s(t)}_{\substack{\text{Attitude}\\ \text{towards H}\\ \text{at time t}\\ \text{due to}\\ \text{active actions}}} \\
& + \underbrace{\xi_{HG}\left(s,\underline{y}(t)\right)G_H(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{H-actions that are perceived}\\ \text{as good}}} - \underbrace{\xi_{HB}\left(s,\underline{y}(t)\right)B_H(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{H-actions that are perceived}\\ \text{as bad}}} \\
& + \underbrace{\xi_{IB}\left(s,\underline{y}(t)\right)B_I(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{I-actions that are perceived}\\ \text{as bad}}} - \underbrace{\xi_{IG}\left(s,\underline{y}(t)\right)G_I(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{I-actions that are perceived}\\ \text{as good}}} \\
& + \underbrace{\sum_{j\neq s}\kappa_{sj}\, f\left(y_s(t),y_j(t)\right)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{due to influence of other}\\ \text{subpopulations}}} \qquad (2)
\end{aligned}
$$

Example of initial condition: $A_s(0)=0$ for $s\in\{1,2,...,S\}$.

Example for specification of $\xi_{HG},\xi_{HB},\xi_{IG},\xi_{IB}$:

$$\xi_{HG}\left(s,\underline{y}(t)\right)=\left(1-p_s(t)\right),\xi_{HB}\left(s,\underline{y}(t)\right)=p_s(t),$$
$$\xi_{IG}\left(s,\underline{y}(t)\right)=p_s(t),\xi_{IB}\left(s,\underline{y}(t)\right)=\left(1-p_s(t)\right) \tag{3a}$$

The greater the support for I (respectively H) in a subpopulation, the greater is the mean change in the attitude of the subpopulation towards H that are due to H-Actions that are perceived as good (respectively bad). The greater the support for I (respectively H) in the subpopulation, the greater is the mean change in subpopulation attitude towards H as a result of I-Actions that are perceived as bad (respectively good). There are other possibilities.

Examples for the other subpopulation influence function f:

Let S_s be the (constant) size of subpopulation s

$$f\left(y_s,y_j\right)=\frac{S_s}{S_s+S_j}y_s+\frac{S_j}{S_s+S_j}y_j; \tag{3b}$$

the mean change in attitude towards H due to the attitude of another subpopulation depends on the relative sizes of the two populations.

$$f\left(y_s,y_j\right)=\frac{e^{\left|a_s-a_j\right|}}{1+e^{\left|a_s-a_j\right|}}y_j+\frac{1}{1+e^{\left|a_s-a_j\right|}}y_s; \tag{3c}$$

the mean change in attitude towards H due to the attitude of another subpopulation depends on how close their basic attitudes towards H are.
Other examples are possible.

The total attitude of subpopulation s at time t towards H is

$$y_s(t)=a_s+A_s(t) \tag{4}$$

Therefore, the measure of subpopulation s support for H at time t is

$$p_s(t)=\frac{e^{\left[a_s+A_s(t)\right]}}{1+e^{\left[a_s+A_s(t)\right]}} \tag{5}$$

Example 1: A Model with One subpopulation and No Feedback

There is one subpopulation. All of the coefficients in the equations are constants, (do not depend on $\underline{y}(t)$). In particular γ_I and γ_H are constants. Letting $t \to \infty$ in equations (1a-1d) results in

$$G_H(\infty) = \lambda_H \gamma_H \frac{1}{\mu_{HG}} \tag{6a}$$

$$B_H(\infty) = \lambda_H [1 - \gamma_H] \frac{1}{\mu_{HB}} \tag{6b}$$

$$G_I(\infty) = \lambda_I \gamma_I \frac{1}{\mu_{IG}} \tag{6c}$$

$$B_I(\infty) = \lambda_I [1 - \gamma_I] \frac{1}{\mu_{IB}} \tag{6d}$$

The limiting mean number of active H-actions that are perceived to be good (respectively bad) is $\frac{\lambda_H \gamma_H}{\mu_{HG}}$ (respectively $\frac{\lambda_H (1-\gamma_H)}{\mu_{HB}}$). The limiting mean number of active I-actions that are perceived to be good (respectively bad) is $\frac{\lambda_I \gamma_I}{\mu_{IG}}$ (respectively $\frac{\lambda_I (1-\gamma_I)}{\mu_{HB}}$).

The limiting mean change in attitude during a time period of length h due to active H-actions perceived as good (respectively bad) is $c_{HG} = \xi_{HG} \frac{\lambda_H \gamma_H}{\mu_{HG}} h$ (respectively $c_{HB} = \xi_{HB} \frac{\lambda_H (1-\gamma_H)}{\mu_{HB}} h$). The limiting mean change in attitude during a time period of length h due to active I-actions perceived as good (respectively bad) is $c_{IG} = \xi_{IG} \frac{\lambda_I \gamma_I}{\mu_{IG}} h$ (respectively $c_{IB} = \xi_{IB} \frac{\lambda_I (1-\gamma_I)}{\mu_{IB}} h$).

If the limiting mean change in attitude due to active actions that support H is greater than the limiting mean change in attitude due to active actions that support I:

$$c_{HG} + c_{IB} > c_{HB} + c_{IG}$$

then as $t \to \infty$ the measure of support, $p(t)$, of the subpopulation for H tends to 1.

Discussion: The limiting mean change in attitude depends on the mean time an action remains in active; whether or not an H-action is perceived as good and an I-action is perceived as bad by the sub-population; and the rate at which perceived active actions influence the attitude of the subpopulation. If the sum of mean attitude change due to active H-actions that are perceived by the sub-population as good and active I-actions that are viewed by the sub-population as bad is greater than the sum of the mean attitude change due to active H-actions are viewed as bad and active I-actions that are viewed as good, then in the long run the subpopulation will support H.

Example 2: A Model with One Subpopulation and Feedback

There is one subpopulation. We assume

$$\gamma_H\left(s,\underline{y}(t)\right)=p_s(t);\gamma_I\left(s,\underline{y}(t)\right)=1-p_s(t);$$

that is, the greater the support the subpopulation has for H (respectively I) the more likely the subpopulation will perceive H-actions as good (respectively bad) and I-actions as bad (respectively good). The other parameters are constants.

Letting $t \to \infty$ in equations (1a-d) results in

$$G_H(\infty)=\frac{\lambda_H}{\mu_{HG}}\frac{e^{a+A(\infty)}}{1+e^{a+A(\infty)}} \tag{7a}$$

$$B_H(\infty)=\frac{\lambda_H}{\mu_{HB}}\frac{1}{1+e^{a+A(\infty)}} \tag{7b}$$

$$G_I(\infty)=\frac{\lambda_I}{\mu_{IG}}\frac{1}{1+e^{a+A(\infty)}} \tag{7c}$$

$$B_I(\infty)=\frac{\lambda_I}{\mu_{IB}}\frac{e^{a+A(\infty)}}{1+e^{a+A(\infty)}} \tag{7d}$$

Discussion: The effect of the actions depends on the mean number of actions initiated during a period, $\lambda_{\bullet}h$; the mean change in subpopulation attitude resulting from active actions during each period which is influenced by $\xi_{\bullet,\bullet}h$; and the mean duration time the actions remain active, $1/\mu_{\bullet,\bullet}$. It also depends on the basic attitude of the subpopulation, $a_{\bullet}$ at time 0.

Some numerical examples

H can control the rate at which its actions are initiated subject to availability of resources. H can also influence, though publicity and control of the media, the mean time active time of actions perceived by the population as enhancing support for H (H-actions perceived as good and I-actions perceived as bad).

Figure 1 displays the measure of support for H as a function of time for three values of basic attitude towards H at time 0, a. The rate at which actions are initiated and their effect on the subpopulation are equal for H and I. In this case the initial basic support for H determines the limiting measure of support H has.

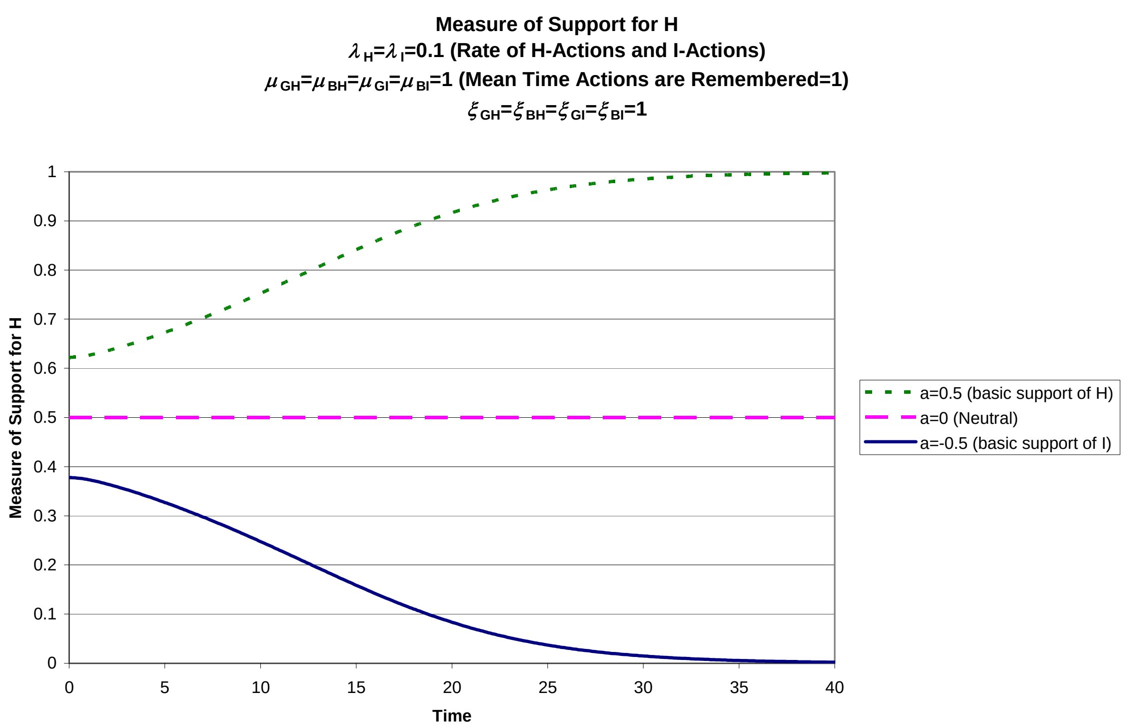

Figure 1

Figure 2 displays the measure of support for H as a function of time for different mean active times actions supporting H (H-actions perceived as good and I-actions perceived as bad) are remembered (active). At time 0 the subpopulation's basic support is for I ($a = -0.5$). The mean active time of actions supporting I (H-actions perceived as bad and I-actions perceived as good) are equal to 1 in all cases. Figure 2 suggest the larger the mean time active time of actions supporting H are remembered (relative to the mean time active time of actions supporting I are remembered), the more likely the subpopulation will support H.

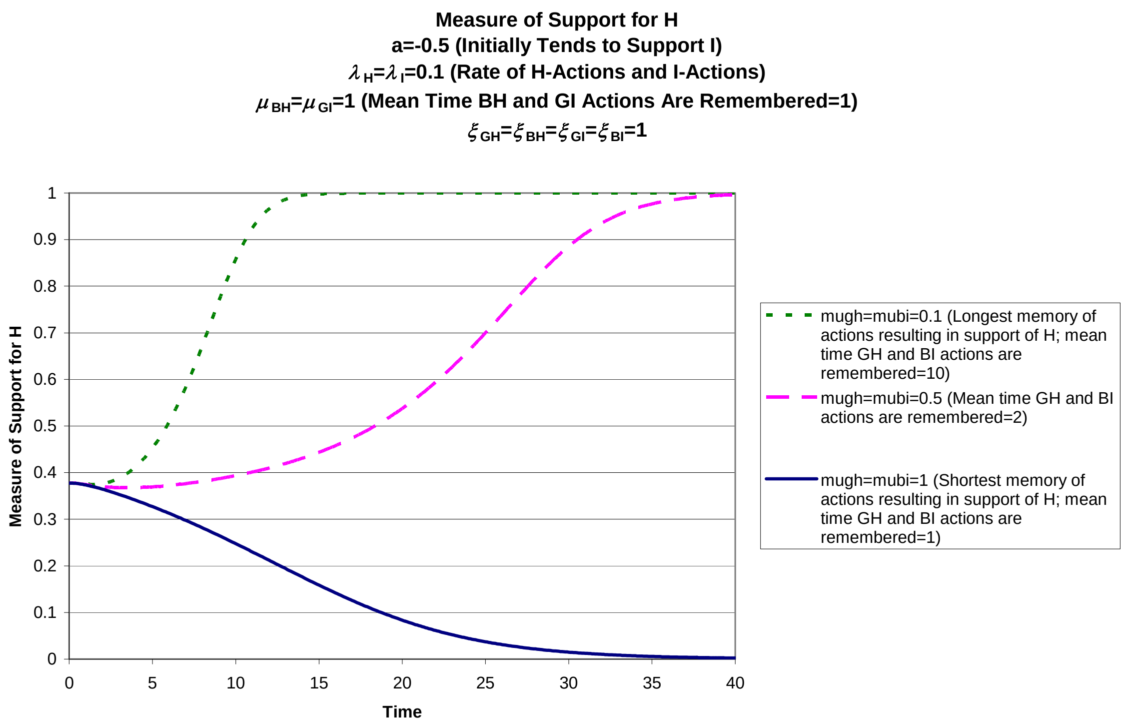

Figure 2

Figures 3a-3c display the measure of support for H as a function of time for different rates at which H takes actions and different mean active times of actions supporting H (H-actions perceived as good and I-actions perceived as bad). At time 0, the subpopulation has basic support for I. The rate of I-actions is 0.1 in all cases. The mean active time of actions supporting I (H-actions perceived as good and I-actions perceived as bad) is 1 in all cases. Figure 3a suggests that increasing the rate at which H-actions are taken without increasing the mean active time of actions supporting H does not overcome the initial support for I. In Figure 3b the rate at which H takes actions are the same as those as Figure 3a but the mean active time of actions supporting H are doubled from 1 to 2. In this case the smallest rate of H-actions results in H gaining the support of the subpopulation; the two larger rates result in the subpopulation strengthening its support for I. Apparently, this is because initially the majority of H-actions are perceived as bad and larger H-action rates incur more actions that are perceived as bad; the memory of actions that support H is not long enough to overcome the initial perception. In Figure 3c the mean active time of actions supporting H are remembered is further increased to 10. In this case H gains support of the subpopulation for each of the H-actions rates considered. There is also a suggestion if the rate of H-actions is large, then support for H may initially decline until the mean number of active actions supporting H increases enough to overcome the initial support for I.

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1 (Rate of I Actions)
μ_{GH}=1, μ_{BI}=1 (Mean Time GH and BI Actions are Remembered=1)
μ_{BH}=μ_{GI}=1 (Mean Time BH and GI Actions are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

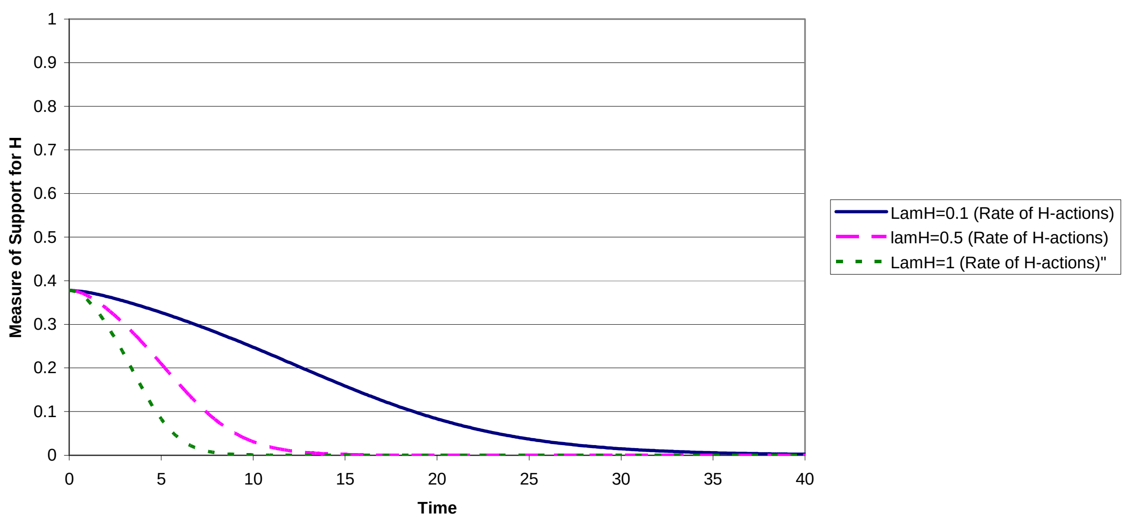

Figure 3a

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1 (Rate of I-Actions)
μ_{GH}=0.5, μ_{BI}=0.5 <u>(Mean Time GH and BI Actions Are Remembered=2)</u>
μ_{BH}=μ_{GI}=1(Mean Time BH and GI Actions Are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

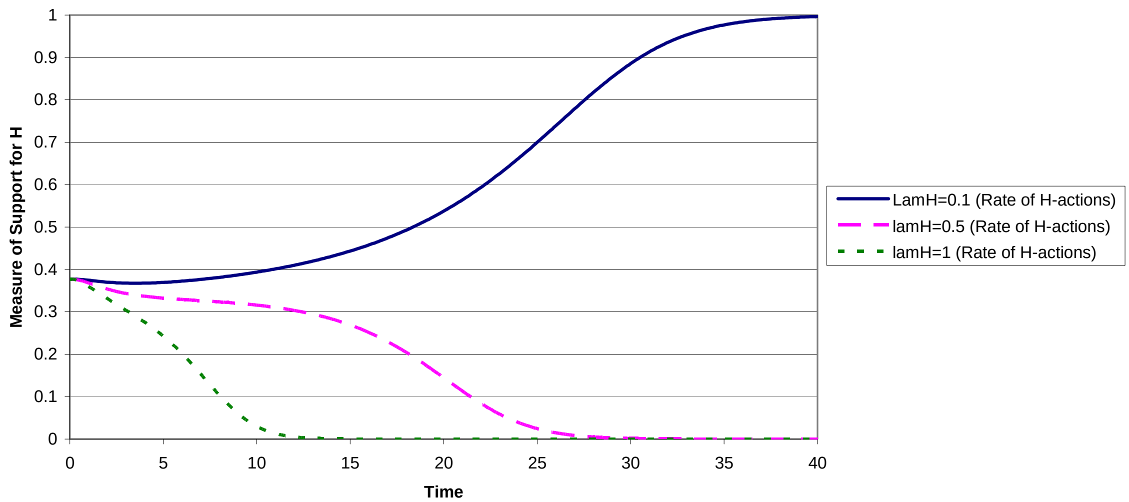

Figure 3b

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1(Rate of I Actions)
μ_{GH}=0.1, μ_{BI}=0.1 <u>(Mean Time GH and BI Actions are Remembered=10)</u>
μ_{BH}=μ_{GI}=1 (Mean time BH and GI Actions are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

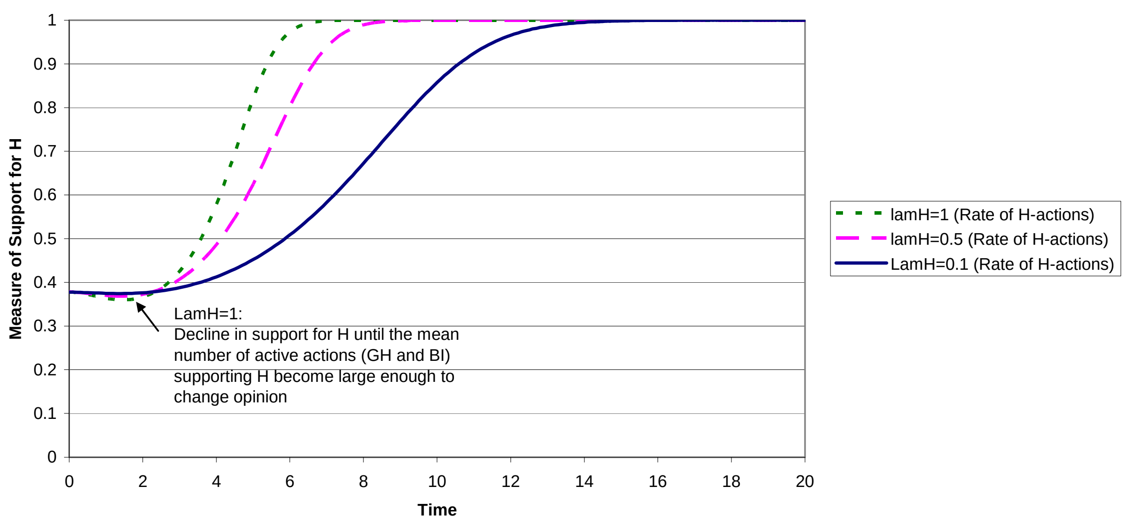

Figure 3c

Conclusions and Further Work

In this model, each actor takes actions. These actions are perceived by the subpopulation as being good or bad. Each action has a positive duration during which it affects the attitude of subpopulations. These simple models suggest the changes in subpopulation attitude is a nonlinear function of the rate at which actions occur; the rate at which actions affect the subpopulation attitude; the mean time an action continues to influence attitudes; and the basic attitude the subpopulation has towards the actors.

In further work we will explore the model for more than one subpopulation. We will develop models to include the beliefs of the actors in relation to those of the subpopulations. We will also include more than one type of action for the actors.

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APPENDIX B: SOCIAL NETWORK MODEL NOTES

The following notes were provided to the TRAC-Monterey RUCG project team by Professor Deborah Gibbons, Graduate School of Business and Public Policy, NPS. These notes were developed by Professor David Krackhardt, The Tepper School of Business, Carnegie Mellon University, for an urban modeling project.[32] They combine general and basic social networking ideas from literature written by Professor Krackhardt. These notes served as one of three models within the TRAC-Monterey RUCG project team analytic social theory model suite. For our research efforts, this model provided a simple foundation for capturing influence exchange within a social network.

[32] David Krackhardt, Notes on Influence Models for Dynamic Settings, The Tepper School of Business, Carnegie Melon University, September 2007.

Notes on Influence Models for Dynamic Settings

1. First, there are several versions of what I will call the fundamental influence model in social systems. In its most basic state, we can say that an individual has an attitude or is likely to engage in a behavior as a function of several factors. These factors can be characterized as primarily attributes (age, sex, education, resources available to them, etc.) and social (influence from friends, contacts, competition, social comparisons, relative depravation, etc.). The first class of factors is traditionally characterized in the standard model as follows:

$$y_i = \mathbf{X}_{ik}\beta_k + \epsilon_i$$

where y_i is the variable of interest (attitude, behavior, performance) on the i subjects, X is a matrix of k explanatory attributes on the i "cases" (people), and ϵ_i is the error term. It is ordinarily assumed that ϵ is IID (the observations around each case are independent of each other), which, along with a few other reasonable assumptions, allows us to estimate the magnitude (β_k) and significance of the effect each of the k variables has on the dependent variable.

We know, however, that these observations are not independent of one another. Quite the contrary, we know that people influence each other on a daily basis. Social network models explicitly take into account such effects through a general model that takes the following form:

$$y_i = X_{ik}\beta_k + \rho_1 \mathbf{W}_{1_{ij}} y_j + \epsilon_i, \qquad \text{where } \epsilon\epsilon' \sim \rho_2 \mathbf{W}_{2_{ij}}$$

W is an ixj matrix that describes the extent to which each neighbor in the network affects each other actor. The $W_1 y$ term, then, is a vector of net direct effects of neighbors' attribute values on any given actor in the system. The W_2 term describes indirect effects in that it captures the extent to which actors' "errors" are not independent but rather autocorrelated (influenced by common sources not otherwise captured in the model).

Estimating these social equations requires going beyond standard econometric models (although MLE solutions have been provided by Doreian, 1984). Friedkin and Johnsen (1999) add to this model a set of dynamics such that one can predict the evolution and equilibrium value of y over time.

Another possible way to look at this process of influence is to model it as a diffusion process. That is, ideas, values, beliefs, and behaviors, all change over time as the participants in the system influence each other to "agree" with them. Diffusion occurs to the extent to which the overall system moves from one set of states (beliefs, etc.) to another. The aforementioned Friedkin-Johnsen model is a reasonable and popular diffusion model.

Another interesting alternative model is the viscosity model (Krackhardt, 1997). It adds to the social influence process an assumption that those with new, innovative ideas will exhibit some enthusiasm for them and tend to proselytize more than those who are tied to the old ways. Formally, the viscosity model has two stages: First, subsets of individuals migrate at certain rates (viscosity rate) along network paths to interact with others in the network. Second, after migration takes place, they encounter new individuals, some proportion of which will "disagree" with their prior position or belief. If this proportion is high enough, they have a probability of converting to the other state (belief). These two stages are modeled as:

Stage 1: New beta (after migration, before adoption) = old beta - outflow + inflow

$$\beta^{t'} = \beta^{t-1} - \frac{[v\mathrm{W} \cdot \beta^{t-1}1']1}{\max[deg(\mathrm{W})]} + \frac{v\mathrm{W}\beta^{t-1}}{\max[deg(\mathrm{W})]}$$

where β is the vector of proportion of adopters for each group; v is the viscosity (visiting) rate of actors as they move from one group to an adjacent one; W is the network of possible migration paths for actors; and the $\max[deg(\mathrm{W})]$ function is a normalizing constant (maximum degree in W) which simply assures us that no migration exceeds the maximum possible.

Stage 2: Conversion rates:

At any time point t, we find the new proportion of adopters in group i (after migration and adoption) as follows:

$$\beta_i^t = \beta_i^{t'} - \sigma\beta_i^{t'}(1-\beta_i^{t'})^{L_a} + \tau(1-\beta_i^{t'})(\beta_i^{t'})^{L_n}$$

where σ is the rate at which adopters become non-adopters when they fail to find like-minded partners among the L_a searched, and τ is the rate at which non-adopters convert to adopters when they fail to find like-minded partners among the L_n searched.

The dynamics in this model are more complicated and have no tractable MLE solution, but results can be reliably obtained through monte carlo simulation. These models demonstrate how the shape and structure of the network itself can determine whether a new idea will successfully diffuse throughout the system.

Each model of network influence can have either a threshold "trigger", which converts an actor from one state to another (such as assumed in viscosity theory), or it can assume people gradually move from one attitude to another over a smooth scale. This deceptively mild assumption actually can make a difference in how the system behaves. Incorporating "many-to-other" (mass media, for example) influences also can make a difference, but these are not as profound.

Some references:

Krackhardt, D. (2001). "Viscosity Models and the Diffusion of Controversial Innovations". In *Dynamics of Organizations: Computational Modeling and Organizational Theory.* Edited by Alessandro Lomi and Erik Larsen. MIT Press, pp. 243-268.

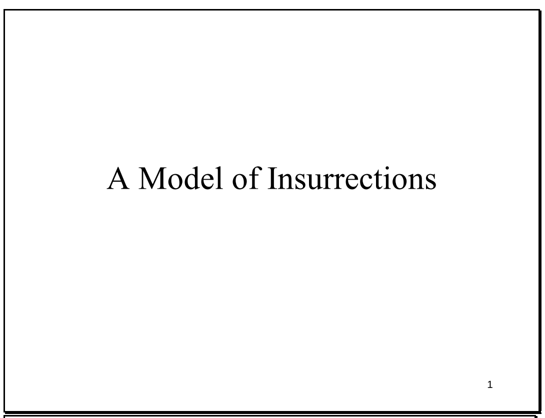
Doreian, P. (1989). "Two Regimes of Network Autocorrelation". In M. Kochen (Ed.) *The Small World.* Pp 280-295, Norwood Ablex.

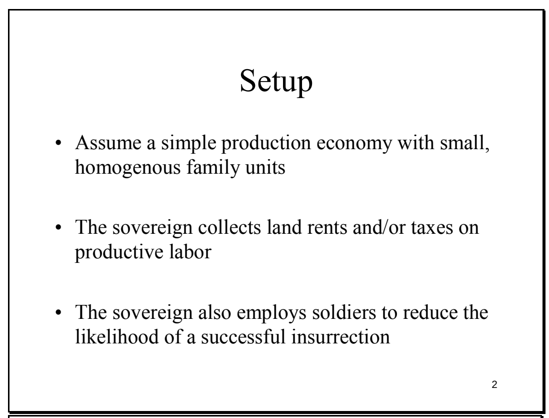
Friedkin, N. E., and E. C. Johnsen (1999). "Social Influence Networks and Opinion Change." *Advances in Group Processes.* Vol 16: 1-29.

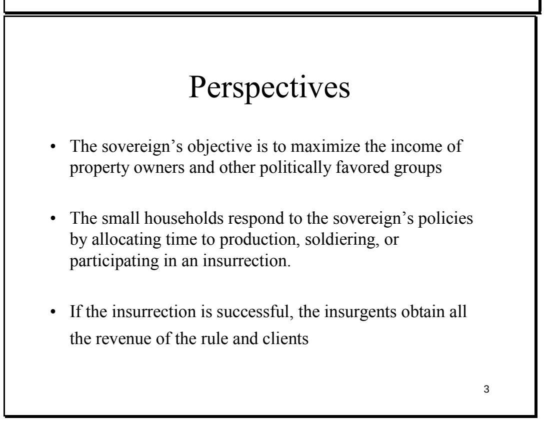
-David

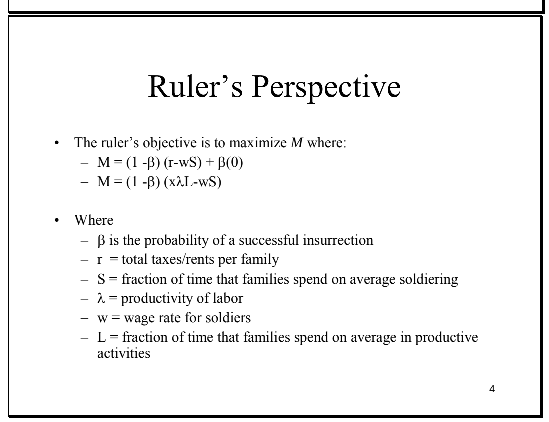
APPENDIX C: ECONOMIC INSURRECTION MODEL POWERPOINT PRESENTATION

The following PowerPoint presentation was provided to the TRAC-Monterey RUCG project team by Professor Robert M. McNab, Graduate School of Business and Public Policy, NPS.[33] This model captures the ability of a sovereign state to maintain support of a civilian populace by registering feedback on functions such as tax rates, wages, time allocations to economic sectors, and probabilities of a successful insurrection. This PowerPoint presentation served as one of three models within the TRAC-Monterey RUCG project team analytic social theory model suite. For our research efforts, this model provided a foundation for constructing various economic representations in an effort to investigate their impacts on attitudinal shifts within a civilian populace.









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33 Robert. M. McNabb, "A Model of Insurrections," PowerPoint presentation given 5 October 2007 at TRAC-Monterey, CA.

Sovereign's Policies

- The net revenue is equal to tax revenue is wage payments to soldiers times the probability of a there not being a successful insurrection
- The sovereign controls x, w, S and moves first
- The sovereign takes the behavioral responses of families as given as well as the technology of production and the insurrection

5

Families

- A family's net income from production is
  - $(1-x)\lambda l$
- A family's net income from soldiering is
  - $(1-\beta)ws - \beta(0) = (1-\beta)ws$
- A family's net income from insurrection is
  - ☐ $\beta(ri/I)$
  - where i is the fraction of time the family devotes to the insurgency
  - where I is the fraction of time that families devote on average to participating in the insurgency

6

Family Income

- Each family takes x, λ, β, w, r, I as given
- Each family chooses l, s, i such that $l+s+i = 1$
- The expected income of a family is
  - $e(y) = (1-x)\lambda l + (1-\beta)ws + \beta(ri/I)$

7

Allocating Time

- Allocation of time to production satisfies
  - $l = 0$ if $(1-x)\lambda l$ < $\max[(1-\beta)w, \beta r/I]$
  - $l = [0,1]$ if $(1-x)\lambda l$ = $\max[(1-\beta)w, \beta r/I]$
  - $l = 1$ if $(1-x)\lambda l$ > $\max[(1-\beta)w, \beta r/I]$
- Allocation of time to soldiering satisfies
  - $s = 0$ if w < $\max[(1-x)\lambda l, \beta r/I]$
  - $s = [0,1]$ if w = $\max[(1-x)\lambda l, \beta r/I]$
  - $s = 1$ if w > $\max[(1-x)\lambda l, \beta r/I]$
- Allocation of time to insurrection satisfies
  - $i = 0$ if $\beta r/I$ < $\max[(1-x)\lambda l, (1-\beta)w]$
  - $i = [0,1]$ if $\beta r/I$ = $\max[(1-x)\lambda l, (1-\beta)w]$
  - $i = 1$ if $\beta r/I$ > $\max[(1-x)\lambda l, (1-\beta)w]$

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Probability of Insurrection

- To model the likelihood of a successful insurrection, we assume that β is an increasing function of I, decreasing function of S
- Define $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$
  - θ and σ represent the technology of insurrection
  - β is larger the larger the θ and σ
- For I=.2, S=.2, $\theta = .2$ and $\sigma = .2$, $\beta = .28$
- For I=.2, S=.2, $\theta = .8$ and $\sigma = .2$, $\beta = .5$

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Elasticity

- We can obtain the elasticity of β with respect to I and σ to examine the percentage increase in soldiers needed to counteract the impact on β of a 1% increase in the size of the insurrection
- $e_{\beta,I} = (1-\theta)(1-\beta)$
- $e_{\beta,\sigma} = -\sigma(1-\beta)\ln s$
- If we assume that s is fixed, then $(1-\theta)/\sigma$ represents the percentage increase in S necessary to offset the influnece of a 1% increase in I

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Participating in the Insurrection

- Given $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$ and that $\beta r/I$ equals the returns from participating in the insurrection, we can find that
- $\beta r/I = (x\lambda l) / (s^{\sigma} + I^{1-\theta})$
- If x>0, L>0, I>0, S>0 then the expected return to insurgent activity is larger larger the θ and σ

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Sovereign's Objective

- Maximize $M = (1-\beta)(x\lambda L - wS)$
- Subject to:
  - $l = 0$ if $(1-x)\lambda l$ < $\max[(1-\beta)w, \beta r/I]$
  - $l = [0,1]$ if $(1-x)\lambda l$ = $\max[(1-\beta)w, \beta r/I]$
  - $l = 1$ if $(1-x)\lambda l$ > $\max[(1-\beta)w, \beta r/I]$
  - $s = 0$ if w < $\max[(1-x)\lambda l, \beta r/I]$
  - $s = [0,1]$ if w = $\max[(1-x)\lambda l, \beta r/I]$
  - $s = 1$ if w > $\max[(1-x)\lambda l, \beta r/I]$
  - $i = 0$ if $\beta r/I$ < $\max[(1-x)\lambda l, (1-\beta)w]$
  - $i = [0,1]$ if $\beta r/I$ = $\max[(1-x)\lambda l, (1-\beta)w]$
  - $i = 1$ if $\beta r/I$ > $\max[(1-x)\lambda l, (1-\beta)w]$
  - $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$

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Resulting Cases

- Case 1: $(L,S,I) > (0,0,0)$
  - $\partial M/\partial L = \partial M/\partial S = \partial M/\partial I$
- Case 2: $(S,I) > 0$, $L = 0$
  - $\partial M/\partial L \leq \partial M/\partial S = \partial M/\partial I$
  - If $L = 0$, then $r = 0$, then $M = 0$
- Case 3: $(L,S) > 0$, $I = 0$
  - $\partial M/\partial I \leq \partial M/\partial S = \partial M/\partial M$
  - If $\theta > 0$, then when $I=0$, $L>0$, $S>0$, then $\beta r/I = \infty$ which violates the K-T conditions
- Case 4: $(L,I) > 0$, $S = 0$
  - $\partial M/\partial S \leq \partial M/\partial I = \partial M/\partial M$
  - If $I>0$, $L>0$, $S=0$ then $\beta=1$ and $M= 0$

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Resulting Cases

- Case 5: $L = 1$, $I=S=0$
  - $\partial M/\partial S \leq \partial M/\partial L \geq \partial M/\partial M$
  - If $L=1$, $I=S=0$, then then $\beta r/I = \infty$
- Case 6: $I=1$, $L=S=0$
  - $\partial M/\partial L \leq \partial M/\partial I \geq \partial M/\partial S$
  - $M=0$
- Case 7: $S=1$, $L=I=0$
  - $\partial M/\partial L \leq \partial M/\partial S \geq \partial M/\partial I$
  - $M=0$

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What Does This Mean?

- If case 1 is relevant, each and every family cannot chose l,s,i to be either 0 or 1
- If case 3 is relevant, each family chooses i=0 but cannot chose l,s = 0 or 1
- This implies that $(1-x)\lambda = (1-\beta)w$ and $(1-x)\lambda \geq \beta r/I$
- In other words, $(1-x)\lambda = (1-\beta)w$ implies that the expected returns from soldiering and production are equal
- $(1-x)\lambda \geq \beta r/I$ implies that if $i>0$ then the expected returns for l,s,i are equal

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Independence from λ

- Combining and taking the f.o.c's of
  - $M = (1 -\beta)(x\lambda L-wS)$
  - $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$
  - $(1-x)\lambda = (1-\beta)w$
  - $(1-x)\lambda \geq \beta r/I$
- $\partial M/\partial L = [\lambda I/(1+\beta L)^2][(1-\beta)I- \beta S]$
- $\partial M/\partial S = [\lambda\beta I/(1+\beta L)][(\sigma(1-\beta)I)/(1+\beta L))-1]$
- $\partial M/\partial I \leq [x\beta L/(1+\beta L)^2][(1-\beta)L + S - (1-\theta)(1-\beta)]$
- β and x, w, s are independent of production technology

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Equilibrium

- Replace i, s, l with I, S, L to obtain
  - $E = (1-x)\lambda L+ (1-\beta)wS +\beta x\lambda L$
- For either $I = 0$ or $I > 0$
  - $E = (1-x)\lambda$
- Adding E to the objective function yields:
  - $E + M = \lambda L$
- So each families expected share of total income should be:
  - $E/(E+M) = (1-x)/L$

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Spreadsheet

σ	θ	Λ	Ι	Σ	ξ	β	M/λ Client Income	E/λ	E/(M+E) Family Income
0.01	0.00	1.00	0.00	0.00	0.49	0.00	0.48	0.51	0.51
0.50	0.00	0.86	0.00	0.14	0.30	0.00	0.16	0.70	0.81
0.99	0.00	0.77	0.00	0.23	0.24	0.00	0.00	0.76	1.00
0.01	0.10	0.94	0.06	0.00	0.45	0.07	0.39	0.55	0.59
0.50	0.10	0.78	0.11	0.11	0.33	0.30	0.11	0.67	0.86
0.99	0.10	0.13	0.84	0.04	0.88	0.95	0.01	0.12	0.95
0.01	0.50	0.74	0.25	0.00	0.50	0.35	0.24	0.51	0.68
0.50	0.50	0.52	0.41	0.07	0.52	0.71	0.05	0.48	0.91
0.99	0.50	0.03	0.95	0.02	0.97	0.98	0.00	0.03	0.99
0.01	0.90	0.61	0.39	0.00	0.57	0.49	0.17	0.43	0.71
0.50	0.90	0.39	0.55	0.06	0.64	0.80	0.03	0.36	0.92
0.99	0.90	0.02	0.97	0.01	0.98	0.99	0.00	0.02	0.98

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GE Benefits

- For a given population, we can estimate the fractions of time devoted to the various activities
- We can explore through simulation the influence of technology on the incomes of the "household" and the sovereign's clients
- The model helps us explore how the policies of the sovereign affect the distribution of household effort

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Drawbacks

- Static GE model through some of the relationships may be endogenous
- Social networks are not defined as agents are assumed homogenous
- No spatial distribution

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Future

- Insurgency only wins or losses. What happens if insurgency results in loss of a percentage of income?
- What happens when risk of participating in soldiering or insurgency increases?
- What about specifying losses associated with various activities?

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Modifications

- Can we model a mechanism by which the reputation of the insurgent movement affects the fraction of time that households are willing to devote to the effort?
- Should we incorporate heterogeneity into the model?
- Complexity is nice, but at what cost..

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APPENDIX D. ABSTRACT SCENARIO "WORKING AGENT PAIRWISE COLOR COMPARISON" SPREADSHEET

Table 12 displays the sidedness settings per agent utilized within our abstract model, designed for mapping the RUCG project team analytic social theory model suite into Pythagoras 2.0.0. These settings help users determine how the various agents will view one another: as unit members, friends, neutrals, or enemies. There is a detailed description of this spreadsheet tool in the *Pythagoras User Manual Version 2.0*.[34] Information provided includes the distance equations it uses and instructions and examples on how to use it.

[34] Northrop Grumman Space and Mission Systems Corps., *Pythagoras User Manual Version 2.0*, 2007, pp. 9-12 - 9-14.

Agent Name	Red	Green	Blue	Unit				Friendly				Enemy			
				Color Radius	Use Red	Use Green	Use Blue	Color Radius	Use Red	Use Green	Use Blue	Color Radius	Use Red	Use Green	Use Blue
All **[HN_PM]** Agents	0	0	255	0	0	0	1	25	0	0	1	230	0	0	1
All **[I_PM]** Agents	0	0	0	12	0	0	1	25	0	0	1	128	0	0	1
All **[Insurgents]** Agents	0	0	12	13	0	0	1	115	0	0	1	218	0	0	1
All **[PF_ILT_HN]** Agents	0	0	178	13	0	0	1	51	0	0	1	153	0	0	1
All **[PF_ILT_I]** Agents	0	0	76	12	0	0	1	51	0	0	1	154	0	0	1
All **[Soldiers]** Agents	0	0	242	13	0	0	1	115	0	0	1	217	0	0	1
All **[CF]** Agents	0	0	255	25	0	0	1	25	0	0	1	230	0	0	1
All **[Terrorist]** Agents	0	0	0	0	0	0	1	25	0	0	1	128	0	0	1
All **[S_ES]** Agents	255	0	242	13	0	0	1	115	0	0	1	217	0	0	1
PF_ES_Left	255	0	65	10	0	0	1	10	0	0	1	11	0	0	1
PF_ES_Center	255	0	132	6	0	0	1	6	0	0	1	7	0	0	1
PF_ES_Right	255	0	189	11	0	0	1	11	0	0	1	12	0	0	1
All **[I_ES]** Agents	255	0	12	13	0	0	1	115	0	0	1	218	0	0	1
PF_24to35	255	0	29	5	0	0	1	5	0	0	1	6	0	0	1
PF_34to55	255	0	45	10	0	0	1	10	0	0	1	11	0	0	1
PF_54to86_1	255	0	65	10	0	0	1	10	0	0	1	11	0	0	1
PF_54to86_2	255	0	75	10	0	0	1	10	0	0	1	11	0	0	1
PF_85to106	255	0	95	11	0	0	1	11	0	0	1	12	0	0	1
PF_105to116	255	0	110	6	0	0	1	6	0	0	1	7	0	0	1
PF_115to127	255	0	121	6	0	0	1	6	0	0	1	7	0	0	1
PF_126to138	255	0	132	6	0	0	1	6	0	0	1	7	0	0	1
PF_137to148	255	0	142	6	0	0	1	6	0	0	1	7	0	0	1
PF_147to168	255	0	157	11	0	0	1	11	0	0	1	12	0	0	1
PF_167to200_1	255	0	178	11	0	0	1	11	0	0	1	12	0	0	1
PF_167to200_2	255	0	189	11	0	0	1	11	0	0	1	12	0	0	1
PF_199to220	255	0	210	11	0	0	1	11	0	0	1	12	0	0	1
PF_219to230	255	0	225	5	0	0	1	5	0	0	1	6	0	0	1

Table 12. Specific "Sidedness" settings per type of agent within our abstract model for representing urban cultural geographies in stability operations.

APPENDIX E. WEIGHTED ATTRIBUTE COLOR CONVERSION SPREADSHEET MODEL

For greater comprehension, this appendix should be utilized in conjunction with the material presented in Chapter III and Chapter IV. There is no direct link between attributes and colors in Pythagoras 2.0.0. Hence, we developed this spreadsheet model as a tool for determining appropriate weighted color splashes per issue within individual subpopulation hierarchical issue structures, dependent on the desired fidelity for the simulation. Fidelity refers to the measurement standards with respect to attribute fluctuations. The smaller the fluctuations measured, the higher the fidelity, and vice versa. In Table 13, the proper "Desired Fidelity" column values to use, with respect to the trigger set methodology described in Chapter III, should be one-half of the input trigger set width. For example, if the attribute trigger set entries measure changes for less than and equal to 200 and greater than and equal to 400, then the appropriate row to use is the (400–200)/2 = 100 row. This is a result of the required resetting of attributes to median values each time an agent returns to the "Initial" alternate behavior. The values listed in each row are derived from the number of issues within the respective hierarchical issue structures, the specific weightings entered, and the color range to attribute range ratio of 0.255 color units per one attribute unit. Once the appropriate row is determined, the listed values represent the proper amount of weighted color splashes to apply per the respective attribute measurements listed in the "Desired Fidelity" column.

We would also like to point out that in the event the listed recommendations in Chapter IV are implemented, this spreadsheet model is still applicable, but the meaning of the "Desired Fidelity" column data will change. With the modified attribute triggers registering increases and decreases vice tracking bounded entries, the desired fidelity will be equal to the modified attribute trigger input values. For example, for the modified trigger, "Attribute 1 increases by: 100," the appropriate weighted color changes will be taken from the "Desired Fidelity" row entry of 100. There will be no need to use one-half the entered trigger setting, because resetting the attributes after each return to the "Initial" alternate behavior will not be required.

The weighting entries in the first row automatically populate the spreadsheet with the proper weighted color splash entries per desired fidelity option. It is imperative to ensure the sum of the weightings is equal to one. Lastly, we will make a comment on the "Color Change Conversion Errors (%) per Trigger Set" column. A trigger set contains a number of attribute triggers equal to the number of issues within a hierarchical issue structure. Hence, the errors presented are representative of the total error accumulated once all of the attribute triggers comprising the hierarchical issue structure have triggered. Individual issues per row induce their own amounts of error from conversion, and the sum of these row errors is what is listed in the last column. These errors vary, depending on the weightings per individual hierarchical issue structure.

Weights	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Actual Color Change Implemented	Proper Color Change Amount	Color Change Conversion Errors (%) per Trigger Set
Issue Name	--	--	--	--	--	--	--	--	--	--			
Desired Fidelity	Color Change for Attribute 1	Color Change for Attribute 2	Color Change for Attribute 3	Color Change for Attribute 4	Color Change for Attribute 5	Color Change for Attribute 6	Color Change for Attribute 7	Color Change for Attribute 8	Color Change for Attribute 9	Color Change for Attribute 10			
10	0	0	0	0	0	0	0	0	0	0	0	2.55	100.00
20	1	1	1	1	1	1	1	1	1	1	10	5.10	96.08
30	1	1	1	1	1	1	1	1	1	1	10	7.65	30.72
40	1	1	1	1	1	1	1	1	1	1	10	10.20	1.96
50	1	1	1	1	1	1	1	1	1	1	10	12.75	21.57
60	2	2	2	2	2	2	2	2	2	2	20	15.30	30.72
70	2	2	2	2	2	2	2	2	2	2	20	17.85	12.04
80	2	2	2	2	2	2	2	2	2	2	20	20.40	1.96
90	2	2	2	2	2	2	2	2	2	2	20	22.95	12.85
100	3	3	3	3	3	3	3	3	3	3	30	25.50	17.65
110	3	3	3	3	3	3	3	3	3	3	30	28.05	6.95
120	3	3	3	3	3	3	3	3	3	3	30	30.60	1.96
130	3	3	3	3	3	3	3	3	3	3	30	33.15	9.50
140	4	4	4	4	4	4	4	4	4	4	40	35.70	12.04
150	4	4	4	4	4	4	4	4	4	4	40	38.25	4.58
160	4	4	4	4	4	4	4	4	4	4	40	40.80	1.96
170	4	4	4	4	4	4	4	4	4	4	40	43.35	7.73
180	5	5	5	5	5	5	5	5	5	5	50	45.90	8.93
190	5	5	5	5	5	5	5	5	5	5	50	48.45	3.20
200	5	5	5	5	5	5	5	5	5	5	50	51.00	1.96
210	5	5	5	5	5	5	5	5	5	5	50	53.55	6.63
220	6	6	6	6	6	6	6	6	6	6	60	56.10	6.95
230	6	6	6	6	6	6	6	6	6	6	60	58.65	2.30
240	6	6	6	6	6	6	6	6	6	6	60	61.20	1.96
250	6	6	6	6	6	6	6	6	6	6	60	63.75	5.88
260	7	7	7	7	7	7	7	7	7	7	70	66.30	5.58
270	7	7	7	7	7	7	7	7	7	7	70	68.85	1.67
280	7	7	7	7	7	7	7	7	7	7	70	71.40	1.96
290	7	7	7	7	7	7	7	7	7	7	70	73.95	5.34
300	8	8	8	8	8	8	8	8	8	8	80	76.50	4.58
310	8	8	8	8	8	8	8	8	8	8	80	79.05	1.20
320	8	8	8	8	8	8	8	8	8	8	80	81.60	1.96
330	8	8	8	8	8	8	8	8	8	8	80	84.15	4.93
340	9	9	9	9	9	9	9	9	9	9	90	86.70	3.81
350	9	9	9	9	9	9	9	9	9	9	90	89.25	0.84

Weights	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Actual Color Change Implemented	Proper Color Change Amount	Color Change Conversion Errors (%) per Trigger Set
Issue Name	--	--	--	--	--	--	--	--	--	--			
Desired Fidelity	Color Change for Attribute 1	Color Change for Attribute 2	Color Change for Attribute 3	Color Change for Attribute 4	Color Change for Attribute 5	Color Change for Attribute 6	Color Change for Attribute 7	Color Change for Attribute 8	Color Change for Attribute 9	Color Change for Attribute 10			
360	9	9	9	9	9	9	9	9	9	9	90	91.80	1.96
370	9	9	9	9	9	9	9	9	9	9	90	94.35	4.61
380	10	10	10	10	10	10	10	10	10	10	100	96.90	3.20
390	10	10	10	10	10	10	10	10	10	10	100	99.45	0.55
400	10	10	10	10	10	10	10	10	10	10	100	102.00	1.96
410	10	10	10	10	10	10	10	10	10	10	100	104.55	4.35
420	11	11	11	11	11	11	11	11	11	11	110	107.10	2.71
430	11	11	11	11	11	11	11	11	11	11	110	109.65	0.32
440	11	11	11	11	11	11	11	11	11	11	110	112.20	1.96
450	11	11	11	11	11	11	11	11	11	11	110	114.75	4.14
460	12	12	12	12	12	12	12	12	12	12	120	117.30	2.30
470	12	12	12	12	12	12	12	12	12	12	120	119.85	0.13
480	12	12	12	12	12	12	12	12	12	12	120	122.40	1.96
490	12	12	12	12	12	12	12	12	12	12	120	124.95	3.96
500	13	13	13	13	13	13	13	13	13	13	130	127.50	1.96

Table 13. Spreadsheet model for determining appropriate weighted color splashes per attribute per hierarchical issue structure.

APPENDIX F. EXPONENTIAL TRIGGER TREES

Exponential trigger trees result from attempting to build embedded trigger sets. As stated in III.D.1.e, embedded triggers refer to the process of building every possible combination of attitudinal stances that agents can adopt at any time period during the simulation. More importantly, because we must input attribute trigger bounds, we must construct every possible order in which agents can travel through all possible alternate behaviors. In other words, we must know which alternate behaviors agents came from in order to build the appropriate possible exits. As a result, the number of possible trigger options that must be built to account for every possible order in which agents can traverse every possible alternate behavior, grows exponentially. The number of trigger options is also dependent on the desired fidelity and the number of attributes utilized, but neither of these is as influential on the trigger option count as the exponential characteristic.

We use Figure 33 as an example for illustrating the exponential growth rate for building embedded triggers. Figure 33 displays an example scenario with three attributes initially set to 475 and model fidelity of 50. The number of "Levels" is dependent on the initial attribute values and the desired fidelity. For this example, the number of levels is nine for the lower end and ten for the upper end; it takes nine decrements of 50 from 475 to reach values less than 50, and ten increments of 50 from 475 to reach values greater than 950. Another way to conceptualize levels is by determining the number of triggers required to travel from the initial attribute settings to the attribute range endpoints of 0 and 1,000 using the chosen fidelity for the model. The number of trigger options presented in our example is approximate due to reductions at the endpoints. If, during the simulation, agents reach either 0 or 1,000, there is only one direction in which they can go with respect to trigger options. However, the loss at the endpoints is insignificant in the presence of the exponential characteristic.

The approximate number of trigger options is captured by the following expression:

$$\min \approx \sum_{i=1}^{Levels} (A)^i \leq T \leq \sum_{i=1}^{Levels} (2A)^i \approx \max$$

Where:

- T = number of trigger options
- A = number of attributes modeled
- Levels is dependent on initial attribute values and desired fidelity

The minimum expression represents the best-case scenario for required trigger options by representing the situation where an agent always satisfies a bound in only one direction. This means that the agent only travels in one direction from start to finish. The maximum expression represents the worst-case scenario, where agents travel through every possible combination of the three attribute settings in every order possible. The important insight is that both the minimum and the maximum number of trigger options required are exponential. Therefore, we determined embedded triggers impractical and did not attempt to determine the exact number of trigger options or exact reductions at the endpoints. With just three attributes, as shown in Figure 33, the required number of trigger options is greater than twelve million, assuming only nine levels.

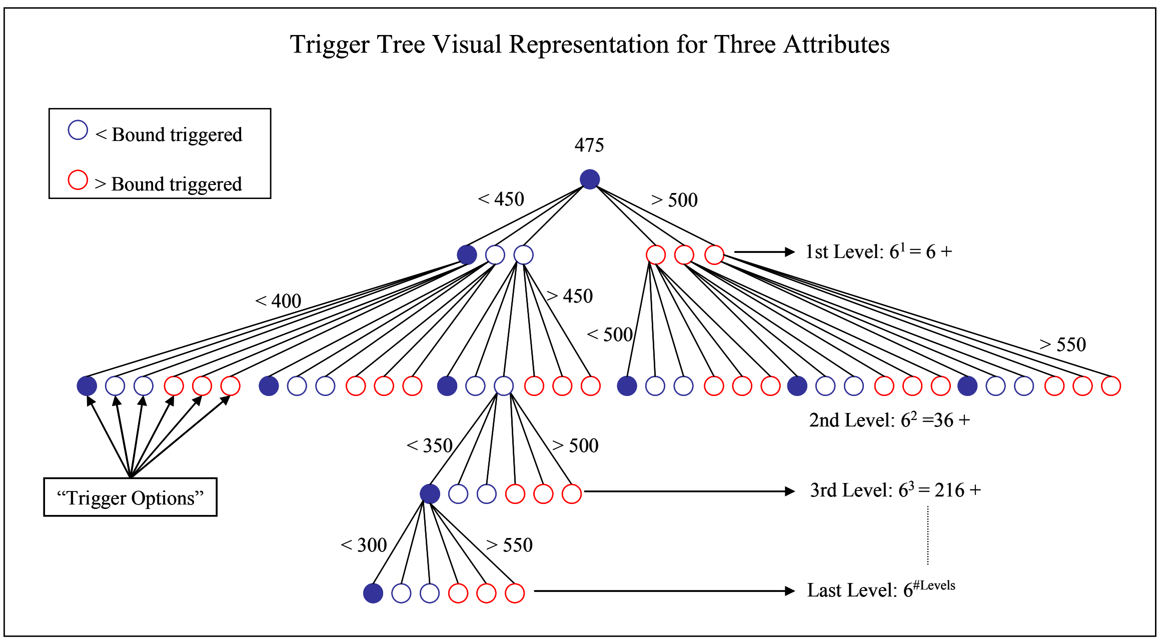

Figure 33. Visual representation for embedded trigger tree exponential growth rate. [Best viewed in color]

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